COLD-REDUCTION SHEET MILL AT PITTSBURG, CALIFORNIA.

THE Columbia Steel Company, of Pittsburg, California, is one of the subsidiary undertakings of the United States Steel Corporation, and operates what is stated to be the only cold-reduction mill of its kind in the Western States. At one time, the Company produced sheets and tinplate by the old hot-pack rolling process. Tinning was given up during the recent war because of the shortage of tin, but the rolling of sheet continued by the old methods until the construction of the new mill, a description of which is given below. An aerial view of the plant is reproduced in Fig. 1, herewith, and Figs. 2 to 6, on succeeding pages, and Figs. 7 and 8, on page 784, show some of the processes and equipment. For these illustrations, and for the particulars which follow, we are indebted to Mr. Laurence S. Dahl, vice-president (operations) of the Columbia Steel Company.

Until comparatively recently, the coils of rolled steel which are the raw material of the Pittsburg mill were obtained from other subsidiaries of the United States Steel Corporation, many of them at a considerable distance. After the second World War, however, the Corporation acquired the plate mill of the Geneva Steel Company in Utah, which they had built and operated for the United States Government during the war. Most of the Geneva Company's war-time output consisted of steel plates, rolled in a 132-in. mill not greatly different in design from the modern type of continuous or semi-continuous strip mill. It was practicable, therefore, to convert this mill to roll either plates or hot-rolled strip in long lengths, and this was done. The conversion was completed in 1949, since when the Geneva Company's mill has supplied most of the hot-rolled coils which are re-rolled into cold-reduced sheets and tinplate at the Pittsburg mill. By comparison with the former methods of production, cold-reduction has the advantages of more uniform control of the sheet gauge and dimensions, and, of course, a much higher production rate; and, as cold-rolling permits the use of steels of low phosphorus content, the product has a higher ductility, better resistance to corrosion, and—an important factor for many users—a superior surface finish.

The hot-rolled low-carbon steel coils from the Geneva mill or elsewhere are transported to Pittsburg by rail and are stored until required in a large warehouse adjoining the pickling plant. On withdrawal from the store, they are fed into the pickling line, which has an overall length of about 600 ft., the rear end of each coil being stitched to the front end of the next to maintain continuous operation. The pickling plant comprises a looping pit, five rubber-lined tanks in which the surface oxides on the steel are removed with dilute sulphuric acid and the strip is then rinsed, together with a side-trimmer and a recoiler. The steel strip is oiled during recoiling, and the coils are then transferred by conveyor to the cold-reduction mill itself. Coils can be handled up to a maximum width of 54 in. and a maximum diameter of 58 in. The strip passes through the pickling plant at an average speed of 350 ft. per minute.

The mill is of the five-stand four-high tandem type, and has a finishing speed of 3,900 ft. per minute. The five stands are identical in design, and have cast-steel housings with a post area of 870 sq. in. The work rolls are 21 in. in diameter and 56 in. long on the face, and are carried in four-row roller bearings with an inside diameter of $13\frac{1}{2}$ in. The two back-up rolls in each stand are 53 in. in diameter and 55 in. in length; they are supported in pressure-lubricated radial bearings and located by roller thrust bearings. The driving motors aggregate 16,300 h.p., and are supplied by generators with a total capacity of 19,900 h.p. A fine spray of palm oil is used to lubricate the strip as it passes through the rolls, the oil mist created being drawn off by the exhaust system. The mill has a capacity of about 450 tons of strip per shift of eight hours. At its exit end are a reel and stripper, and a belt wrapper. The reel has a three-section drum, 20 in. in diameter, with a gripper. The belt wrapper has two 12-in. belts, and a double-acting air cylinder giving a traverse of 6 ft. to 8 ft.

There are two oil-circulating systems to lubricate the bearings of the back-up rolls, with two separate systems for recirculating lubricating oil to the screw-down gear, the gear drives, and the pinion stands. There are also two motor-operated centralised pressure systems for greasing the mill roller-bearings, the spindle carrier bearings, and the chuck slides, pressure block screws, splines, etc. Two manually-operated systems supply grease under pressure to the uncoiler and the reel. Soluble oil in water is used to cool the rolls. The exhaust system for recovering the mist produced during rolling has a capacity of 100,000 cub. ft. per minute.

The total reduction in the thickness of the strip is up to 80 per cent. of the original thickness; most of it is effected in the last three stands, the amount ranging from 17 per cent. to 45 per cent. in each stand. There is, of course, a further reduction in the subsequent temper rolling. The reduction accomplished in the mill is partly obtained by tension between the stands, and this may range from 10,000 lb. to 80,000 lb. per square inch in the strip. The original length of a hot-rolled coil as fed into the mill is about a quarter of a mile, which is increased by rolling to a final length of about $1\frac{1}{4}$ miles. It is stated that, in another mill owned by the United States Steel Corporation, and equipped with a similar set of rolls, steel has been cold-reduced to a thickness of 0·0035 in., which is claimed to be the thinnest ever attained on a large five-stand mill in commercial production. The gauge of the strip is controlled to within $\pm$ 0·0005 in. The hardness, as the strip leaves the mill, is approximately 90 Rockwell B.

On leaving the mill, the strip passes to one of the two electrolytic cleaning lines (Fig. 3) for the removal of the rolling lubricant remaining on its surface. Successive strips are welded end to end to give a continuous feed to the cleaning plant, the ends being cut square before welding, by air-operated shears. Similar shears cut out the welds at the exit end of the lines of covered tanks, which comprise, in order, a cleaning section and a scrubbing section, then another cleaning section and scrubbing section, and a final rinsing section. Cleaning is effected by electric current passed through an alkaline solution. The cleaned strip is dried with hot air and then rewound into coils for transport to the annealing department. The speed of travel through the cleaning plant is 1,750 ft. to 2,000 ft. per minute.

The annealing shop, illustrated in Figs. 4 and 5, on page 770, has 30 furnace bases, each large enough to accommodate eight of the cylindrical hoods,

FIG. 1. GENERAL VIEW OF PLANT.

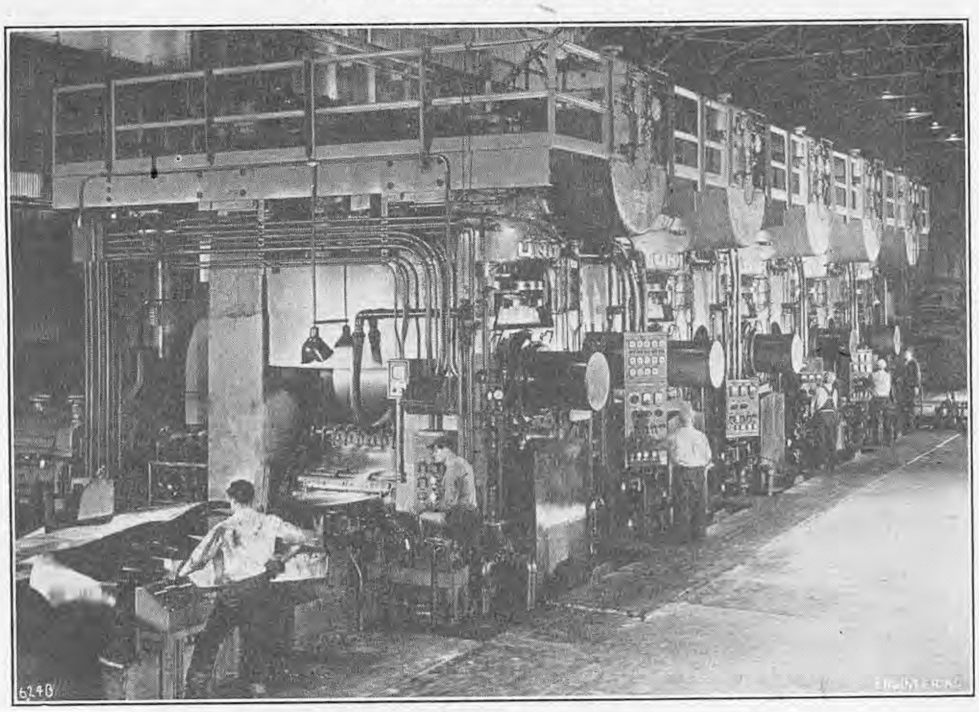


FIG. 2. COLD-REDUCTION MILL.

5 ft. 2 in. in diameter and 13 ft. 9 in. high, and made of $\frac{5}{16}$ in. open-hearth steel plate, to be seen in those illustrations. Each hood covers a stack of four coils, piled to a height of about 12 ft. 6 in. The portable cover-type furnace is lowered by a travelling crane over the group of eight hoods, and rests on a sand seal at the base. The hoods are then filled with inert gas—the product of combustion of natural gas, burned in a controlled-atmosphere generator—to prevent scaling. The furnaces are fired with natural gas, and the coils are annealed at a temperature of 1,350 deg. F., automatically controlled. An eight-point recording pyrometer records the temperature at selected points in each stack. There are ten portable furnaces, which can be used on any of the 30 bases. The coils are taken into and out of the annealing shop on flat cars, as shown, and are handled by an electromagnet from the overhead travelling crane.

The furnace bases are of structural steel, sealed with sand on all four sides, and each having eight circular steel loading plates, mounted on sectional castings. The bottom lining course of each base is of insulating material, $2\frac{1}{2}$ in. thick, and over this is laid insulating concrete and then refractory concrete. There are eight recirculating fans to each base, to ensure satisfactory heat distribution throughout the charge and subsequently to expedite cooling; they are driven by $1\frac{1}{2}$-h.p. motors. Heat is supplied to each furnace through 40 recirculating combustion units of the radiant-tube type, made of nickel-chromium heat-resisting steel, and each provided with its individual proportioning carburettor for fuel and air, a test burner, and lighting torches. The combustion-air fans are of the turbine type, driven by totally-enclosed induction motors. The generators which supply the inert gas are three in number, each with a capacity of 10,000 cub. ft. per hour. Each has a refrigerating unit to cool the prepared gas, thus reducing its dew point to about 40 deg. F. The refrigerator motors are of 7 h.p. and the blowers which supply combustion air to the generators are of 3 h.p.

Oxidation during annealing being effectively prevented by the use of the controlled atmosphere, the annealed coils can be taken directly to the temper mills without further preparation of the surface. The single-stand four-high temper mill, which is illustrated in Fig. 6, opposite, has work rolls 21 in. in diameter and 60 in. long on the face, and back-up rolls 49 in. in diameter. It is driven by a direct-current motor of 1,000 h.p., at a maximum speed of 600 r.p.m.; the supply to the motor is at 600 volts. The maximum speed of rolling is 1,000 ft. per minute of strip from 24 in. to 52 in. wide, but it is equipped also to roll single sheets if desired. If the steel is required by the customer to be supplied in sheet form, the temper-rolled coils are side-trimmed and cut to length in a shearing line, to cut sheets up to 54 in. wide, through which the steel passes at 400 ft. per minute.

The Columbia Steel Company also supply galvanised sheets and these, too, are produced at the Pittsburg plant. Sheets intended for galvanising are transferred from the mill to a batch pickling line, where they are pickled, neutralised, rinsed, and treated to drive off hydrogen. The stacked sheets are then taken to the feed tables of the galvanising line, which comprises pickling tanks, the galvanising pot, a washer, a dryer, and roller levelling machines for flattening the coated sheets.

Strip steel destined for conversion into tinplate sheets passes through one of two four-high two-stand tandem temper mills at about 3,000 ft. per minute, and is supplied in widths from 16 in. to 38 in., with thicknesses which may range from 0·006 in. to 0·060 in. The work rolls of these mills are 18 in. in diameter and 42 in. long on the face, and the back-up rolls are 49 in. in diameter by 42 in. Two-stand tandem mills are used in this line because they ensure greater hardness and stiffness than can be obtained with a single-stand temper mill. The strip coils, which are 20 in. inside diameter and up to 60 in. outside diameter, are taken (whether they are intended for black plate or hot-dipped tinplate) to one of three shearing lines, in which they are side-trimmed, cut to length by a rotary shear, and stacked. Each line is equipped with a flying micrometer and a photo-electric pinhole detector. On the delivery side of

COLD-REDUCTION SHEET MILL.

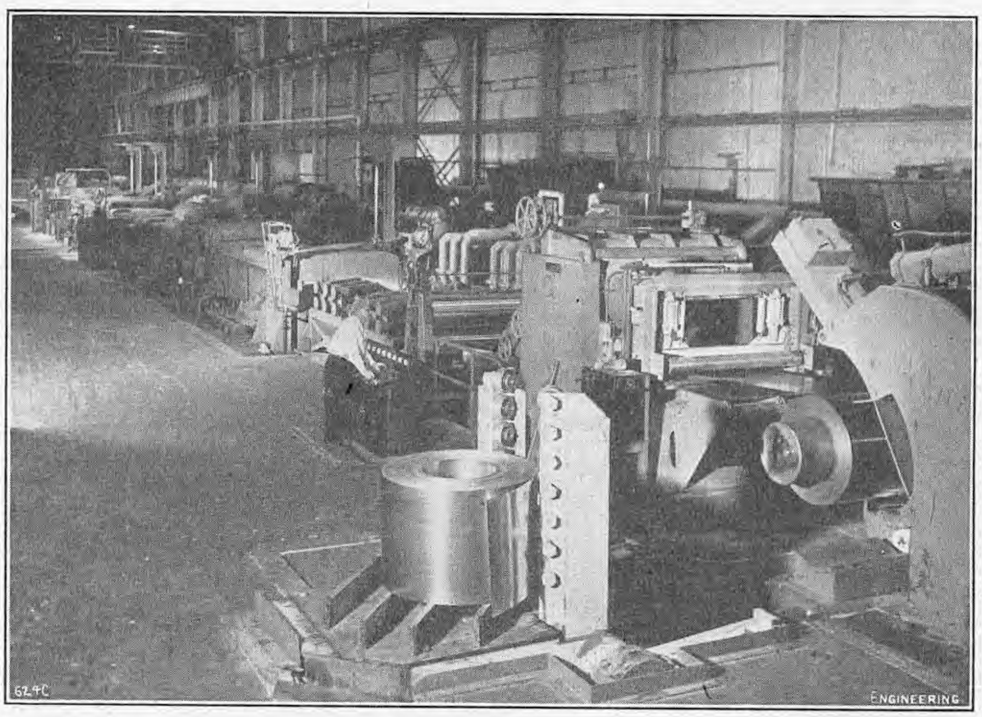


Fig. 3. Electrolytic Cleaning Line.

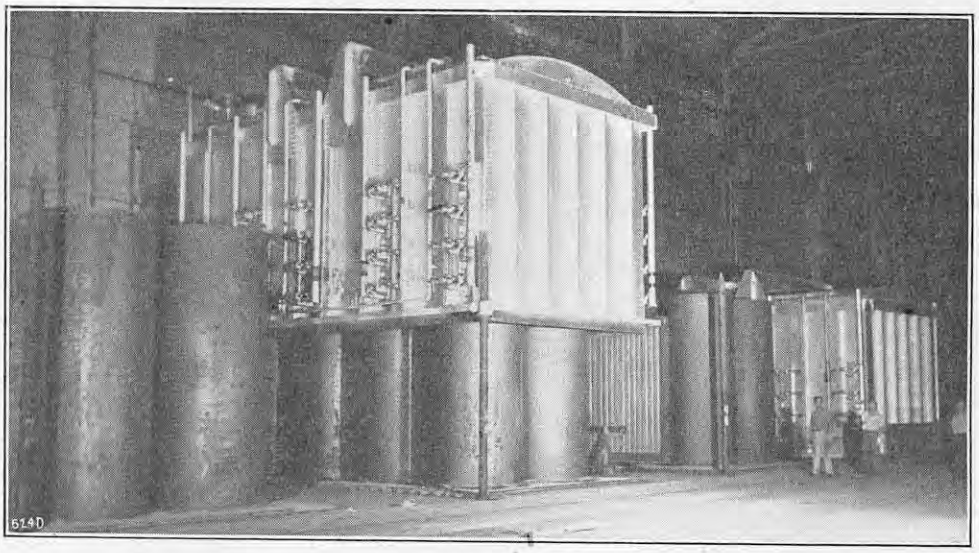


Fig. 4. Annealing Furnaces.

Fig. 5. Stacking Coils for Annealing.

COLD-REDUCTION SHEET MILL.

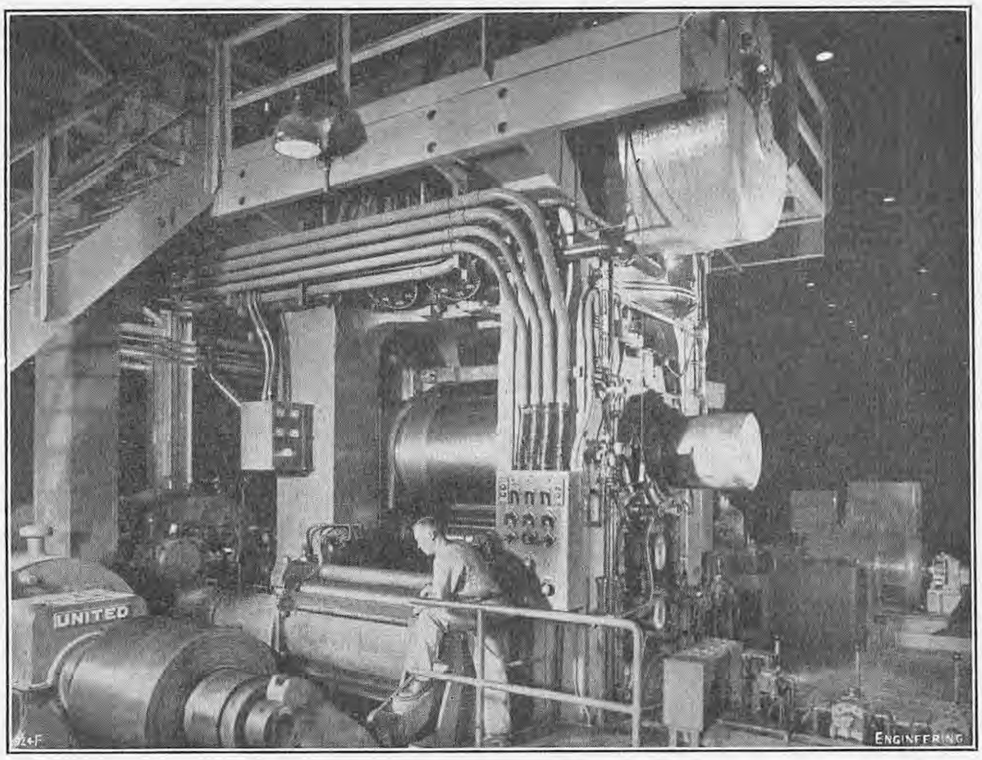


FIG. 6. EXIT SIDE OF TEMPER MILL.

the rotary shear in each line, a classifier sorts the plates into "approved" or "rejected" piles.

There are 14 hot-dip tinning units, each completely equipped so that it can operate independently of the others (Fig. 7, page 784); a feature which is claimed to be unique in hot-dip tinning practice. The general design of the plant was developed as a result of research carried out by the Tennessee Coal, Iron and Railroad Company, also a subsidiary of the United States Steel Corporation. At the entry end of a hot-dip line, the black-plate sheets are fed into an electrolytic pickling unit and thence through a flux bath, into a bath of molten tin, and on to the tinning rolls, which are immersed in palm oil to prevent oxidation and assist uniform coating. Excess oil is removed in a washer containing an alkaline solution and the plates then pass through a branning machine, where they are polished by cloth-covered rolls over which rye or wheat middlings are continuously distributed. They are then re-oiled. A conveyor takes the polished plates to an inspection station, where they are classified as "prime," "mender" or "water-waste" and automatically piled according to their classification. Coated sheets entering the "prime" piler are counted electronically. "Mender" sheets are those which show only coating defects that can be corrected by re-tinning. "Water-waste" sheets are those found unfit for commercial use.

Hot-dipped tinplate is produced in the Pittsburg plant in three coating weights, designated as "common cokes," "standard cokes" and "best cokes," and having in their coatings, respectively, 1·25 lb., 1·5 lb. and 1·65 lb. of tin per base box. The "base box" is equivalent to 112 plates, 14 in. by 20 in. and of any gauge, or a single area of 31,360 sq. in. The thickness of the coating on the hot-dipped "common coke" sheets is only about 66 millionths of an inch, but economic considerations showed, even before the war, the need for sheets with lighter coatings. What is claimed to be the first commercial electrolytic tinning plant for plating continuous strip was built at Gary, Indiana, by a subsidiary of the United States Steel Corporation, and, on the basis of the experience thus gained, electrolytic tinning has been also installed at Pittsburg. In this installation, illustrated in Fig. 8, on page 784, the annealed and tempered coils from the main mill are first uncoiled, trimmed to exact width and recoiled at a maximum speed of 1,800 ft. per minute. An air-operated shear then trims the adjoining ends of the strips, which are seam-welded by a travelling welding-head. The welded strip passes next through pinch rolls, and thence in a loop to a tensioning device which winds the strip into tight coils, weighing up to 30,000 lb. each, for transfer to the electrolytic tinning line.

The several stages in the electrolytic line are continuous and extend over a distance of rather more than 250 ft. At the entry end are two coil-holders, the pinch rolls and guides, a double-cut shear, and a welding machine to join successive coils end to end. From the welder the continuous strip drops into a 60-ft. looping pit, this slack loop enabling the subsequent processes to operate continuously while the incoming strip is momentarily stopped for welding. The uncoated strip is cleaned, rinsed, pickled, again rinsed (to remove the pickling salts and solution) and then fed into four successive electroplating tanks. The weight of the coating is regulated by varying the current density for a given strip width and speed, and an integrating meter shows directly the weight of tin that has been applied. On leaving the fourth plating tank, the strip is rinsed and then passes through a vertical muffle furnace in which it is resistance-heated to melt the tin into a uniform coating. It is then quenched in water, chemically cleaned and, finally, passed through a machine in which a protective coating of oil emulsion is applied.

The tinned and oiled strip is drawn over a hump conveyor to a combined roller leveller and rotary flying shear, which cuts it into sheets of the desired length. The sheets fall on to classifying conveyors for sorting into "prime plate," "menders" and "off-gauge plate." The prime plates are counted into bundles according to requirements and are taken on a roller conveyor, at right angles to the tinning line, for weighing and packing. Off-gauge and mender plates are transferred from the pilers to a reclassification line for further inspection and, if recoverable, for additional treatment.

The electrolytic tinning plant can produce tin-coated sheets 0·007 in. to 0·0143 in. thick, 18 in. to 34 in. wide and up to $37\frac{1}{2}$ in. long at speeds up to 650 ft. per minute. The coating is checked by a thickness gauge which can measure to within 6 ten-millionths of an inch, the sheet of tinplate being exposed to an X-ray beam and the secondary rays, reflected from the steel beneath the coating, being measured with a Geiger counter. The radiation which reaches the Geiger counter is in inverse proportion to the thickness of the plating.

LITERATURE.

Facts, Files and Action in Business and Public Affairs. Part One, Sources and Backgrounds of Facts.

By DR. J. EDWIN HOLMSTROM. Chapman and Hall, Limited, 37, Essex-street, London, W.C.2. [Price 36s. net.]

THE best way to describe the nature of this book is to relate it to Dr. Holmstrom's work *Records and Research in Engineering and Industrial Science*, first published in 1940, and of which a favourable review of the considerably enlarged second edition appeared in the issue of ENGINEERING for January 9, 1948. The purpose of that book was to serve as a guide to sources of information in the engineering and scientific fields; the constitution and activities of research organisation and professional institutions were described, and methods of collecting and utilising data dealt with. The present work sets out to extend the same treatment to "business and public affairs." This expression covers a very large field and it is not surprising that three volumes have been found necessary to cope with the formidable task which the author has set himself. The present Part 1 deals with "Sources and Backgrounds of Facts"; Part 2, now in the press, is to cover "Filing, Indexing and Circulation" and Part 3, in preparation, "The Planning and Ensuing of Action."

It is stated in the preface, that "policy needs to be formulated on a broad foundation of all the relevant facts, not as we should like them to be but as they actually are." This dictum may certainly be accepted as an expression of what is desirable, but it is to be feared that, in public affairs, policy is frequently based on "facts" as the policy-makers would like them to be. It is doubtful if the remarkable collection of information present in this book will have much effect on many of those who control public affairs, but it may prove of very considerable service to many who have to deal with industrial problems. As an example, when a firm are considering setting up a factory in some part of the country remote from the scene of their previous activities, in choosing one of a number of possible sites it is necessary to collect information about local government, population, transport facilities, social services, power supply and other matters. Data bearing on such subjects can be, and are, collected from various sources, but it would be a considerable convenience, and might save much fruitless inquiry, if a guide to sources of information on these vary varied considerations were available. This book is such a guide.

It contains a bibliography listing 946 publications; these consist not only of books in the ordinary sense, but reports of many kinds and various articles in periodicals. A bibliography of this extent may appear to be too large to be of practical use; but this is not the case, as it is divided into sections each concerned with some specific field, and a reader who is seeking information about say "Transport by Hand" is faced with only 36 entries. Although, in a sense, the bibliography is the most important part of this guide, and it is stated that "it is one of the main objects of this book to mention" the publications contained in it, it would be incorrect to assume that this compilation is a mere list of sources. It contains 30 chapters "each dealing with a different facet of the national life and economy" and the various items given in the bibliography are related to the general considerations and explanations which make up the chapters. In this way the relative importance, or particular value, of the various bibliographical items may be judged.

The range of the book may be indicated by giving the titles of a few chapters, selected at random—Economics and Sociology for Planning; Geography; Local Government Services; Public Finance. Of this brief list, it may be said that the chapter on geography contains information about what maps are available and who publishes them. The descriptive matter in the chapters is well written and, although its main purpose is to give information, personal comment or criticism by the author is not lacking; it is remarked that the index to the late Professor Levy's *The Shops of Britain* is "infuriatingly inefficient." Dr. Holmstrom enlivens his pages with various *obiter dicta*, as, for instance, about the "silly use of the word 'target'," with which most, but not all, educated people will find themselves in agreement. The whole book is one more example of the author's remarkable industry.

ELASTIC STRESS ANALYSIS OF MULTI-BAY SINGLE-STOREY FRAMEWORKS.

By E. H. BATEMAN, M.A., Ph.D.

THE type of structure analysed in this article—the type with rigid joints and fixed footings—is used by Southwell* as an example of "problems which are too complex for exact mathematical treatment," and for which solutions may be obtained "by experiments on models." The difficulty of obtaining an analytical solution by known methods is further evidenced by the omission of the multiple-bay fixed-base frame from the publications of Gehler,† Kleinlogel‡ and other investigators who have tabulated so many results for frameworks of lower redundancy and simpler elevation.

The recent development by L. A. Beaufoy and A. F. S. Diwan§ of a method described as "a mathematical analogue of the experimental one using unloaded models," which they have applied successfully in this context, adds support to the view that this is a problem which tends to expose the limitations of the several established methods of analysis. Subsequent to the preparation of the substance of this article early in 1949, there has been considerable progress in the construction of electronic computers capable of performing the matrix operations on which the present method depends. Hence, although it was devised as a logical extension of the classical strain-energy approach, with manual computation in view, this matrix method may well prove to be the best way of ordering the numerical data of a problem for high-speed automatic computing.

The structure illustrated in Fig. 1, herewith, as a series of polygonal arches supported on vertical pillars, is a symmetrical form suitable for an engineering design, but the general case is that in which the pillars need not be vertical, nor the footings at the same level, nor the arches symmetrical. The problem is to find the load vector, representing the bending moment, axial force, and shear force, at any point due to any applied load or combination of loads. Though the analysis is specially directed to the solution of this particular problem, the methods developed in this paper have a wider application in the theory of structures.

The solution is established for the general case in terms of matrices formed from coefficients which describe the geometrical, elastic, and loading data of the problem. Special consideration is given to the construction of the operational matrix, the inversion of which is the principal difficulty in problems of redundant structures. This matrix contains only the geometrical and elastic data of the problem, and the possibility of obtaining a solution depends on the orderly and economical statement and manipulation of the design data. One of the principal contributions to the solution is a theorem‖ stated by the writer in 1933, which expresses the strain energy in a form in which all quantities not material to the final solution are discarded by the formation of the equations of minimum strain energy.

The other principal contributions are the choice of the most convenient axes for introducing the geometry of the framework, and the use of matrix algebra* to organise the design information, and to reduce and control the analysis. In this system, the determination of the load vector at any point, in the general unsymmetrical case with a large number of bays and with any combination of applied loads, is no longer beyond computation, and the complete solution for a two-bay or three-bay frame becomes an eminently practicable operation of design analysis. A symmetrical case, with a small number of frame members, is chosen for the numerical example, because it fully illustrates the essential features of the solution with the minimum of arithmetic. The introduction of asymmetry, and the increase in number of frame members which may be necessary to account for the curvature or variable section of frame members, will increase the labour of computation, but will not materially affect the form of the operational matrix, and, therefore, will not increase the computation involved in forming its reciprocal.

In the analysis of statically indeterminate structures, the indeterminate quantities may be taken either as forces or as displacements.† The choice will depend on whether it is easier to write down the equations of statical equilibrium of the panel points, or the equations of positional and elastic continuity. If the form of the structure is a grid or network, the displacement method is the more suitable, because the number of independent displacements will be small in relation to the total number of frame members. In the present problem, a complete displacement vector, of rotation and translation in two directions, is needed to specify the position of intermediate panel points in the arch sections. The equilibrium equations are simpler to form, and the analysis is therefore conducted in terms of forces instead of displacements.

The problem is essentially one of flexure, and the direct forces and shear forces in the frame members are assumed to make no contribution to the total strain energy, though they must, of course, be included in the final stressing of the framework. While the error introduced by this assumption may sometimes be appreciable‡—e.g., $7\frac{1}{2}$ per cent. in a representative multi-storey framework—the effect can be ignored in a single-storey frame, and it may be assumed to have no practical significance in a frame with arched or pitched roof-members.

The stress at any point in the framework arises from the bending moment and two force components acting at that point, but it is more convenient to work with a load vector comprised by the bending moment and two thrust moments, so that there are N statically-indeterminate moment vectors for the single-storey framework of N bays. If these moment vectors are taken to act on sections through the arches rather than in the pillars or at the pillar footings, there is only one unknown vector in operation for each arch member and only two for each intermediate pillar.

Except in the most elementary problems, the strain energy cannot be stated directly in terms of the unknown vectors and the applied forces, but the introduction of the unknown moments at the ends of the frame members leads to a very simple form for the statement of total strain-energy.* These unknown end moments are related to the indeterminate moment vectors and the applied forces by the equations of statical equilibrium of the panel points, and these equations appear in a form suitable for immediate expression in matrix notation. The equations of minimum strain energy are set up by using the matrix of the unknown moment vectors as the independent variable in the differential operator. The relevant differential coefficients are obtained in matrix form from the equations of equilibrium.

Fig. 1.

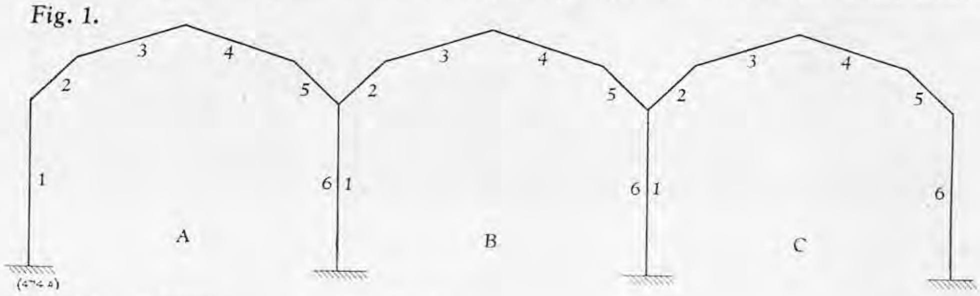


Fig. 2.

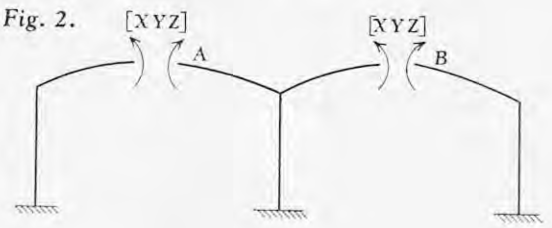


Fig. 3

Fig. 4.

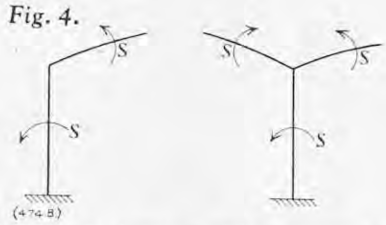
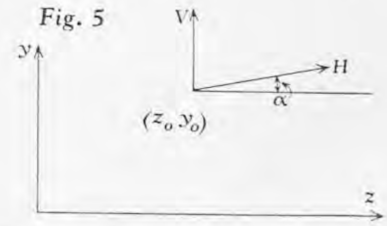


Fig. 5



There are 2R equations of equilibrium and 3N strain-energy equations in a framework of R members and N bays. They are expressed as two simultaneous matrix equations, and the elimination of the unknown end moments results in the formation of the operational matrix. This is a square matrix of order 3N, which is considered as a matrix of order N in which the elements are third-order square matrices. As a result of the proper choice of the points of action of the moment vectors, this matrix of matrices consists of the three major diagonals with all other elements zero. The next operation is to eliminate the non-diagonal elements of the diagonal sub-matrices, and this is done by finding a suitable origin and orientation of coordinate axes for the moment vector acting in each bay. The leading diagonal can then be reduced to unity by simple multiplication, since the reciprocal of a diagonal matrix is the matrix of the reciprocals of the diagonal elements.

The operational matrix is now in a form in which its reciprocal can be readily obtained for a two-bay or three-bay frame, and from which a numerical reciprocal for a large number of bays is not beyond reasonable, if lengthy, computation. Three methods

* *Theory of Elasticity*, by Sir Richard Southwell, F.R.S. Oxford University Press, 1941.

† *Der Rahmen*, by W. Gehler. Berlin, 1925.

‡ *Rahmenformeln*, by A. Kleinlogel. Berlin, 1945.

§ "Analysis of Continuous Structures by the Stiffness Factors Method," by L. A. Beaufoy and A. F. S. Diwan. *Quarterly Journal of Mechanics and Applied Mathematics*, vol. II, Part 3, Sept., 1949.

‖ "The Strain Energy of an Elastic Bar," by E. H. Bateman. *Phil. Mag.*, December, 1933, page 1128.

* *The Theory of Determinants, Matrices and Invariants*, by H. W. Turnbull, F.R.S. Blackie and Son, 1948.

† "The Stress Analysis of Continuous Frames," by E. H. Bateman. *The Structural Engineer*, October, 1936.

‡ "The Effect of Longitudinal Strain in the Members of an Elastic Network," by E. H. Bateman. *Phil. Mag.*, January, 1935, page 59.

* "The Strain Energy of an Elastic Bar," by E. H. Bateman. *Phil. Mag.*, December, 1933, page 1128.

of inversion are given in Appendix I: (a) the inversion of a matrix of non-commutative elements in a form which corresponds with that normally used for an arithmetical matrix; (b) a method of inversion by binomial expansion; and (c) a method of successive approximation, and correction of approximate solutions, by remainder distribution. When the reciprocal of the operational matrix has been found, the solution matrices and the determination of the effects of the applied loads follow by straightforward matrix multiplication.

The more important application of the structural form under discussion is, perhaps, the framework of a factory building or an aircraft hangar, rather than the viaduct mentioned by Southwell. In the former applications it is common practice, for the want of a workable method of analysis, to introduce pin joints at the pillar footings, and, in larger structures,* to design each bay as an independent two-hinged arch, thus doubling the intermediate pillars. It may be open to argument, perhaps, whether it is better to use the roof of a structure to support the pillars rather than, as might seem more natural, to use the pillars to support the roof, but there is a strong case for presuming that the fixed-base structure must result in a significant saving in material. A discussion of the economics of different forms of construction is outside the scope of this paper, but a dictum of Cox† gives immediate substance to the argument that the additional design cost of a fixed-base structure should lead to a substantial reduction in overall cost, in a structure of large spans or a large number of similar frames. "The minimal weight of a structure," he observes, "is represented by a redundant framework which is for all values of the structure-loading coefficients lighter than the lightest possible simply stiff framework."

purely mathematical development. In particular, suffixes are not always fully detailed, and some abbreviations are made without explicit definition. The convention of matrix multiplication is that the left-hand matrix in a product controls the number of rows, and the right-hand the number of columns, in the product matrix. Brackets { } are used to designate single-column matrices.

The meaning of some symbols rests on the context in which they appear, but the principal symbols and conventions are given below.

- M, N the unknown moments at the ends of a frame member.
- F, G the corresponding known fixing-moments due to applied loads.
- m, n defined by the equations $M = m + F$, $N = n + G$.
- S the moment of the applied forces about any panel point, including only those forces which occur between the panel point concerned and the point(s) of action of the indeterminate vector(s) acting on the said panel point.
- f, g defined by the equations $f = F - S_m$, $g = G - S_n$.
- $[XYZ]_A$, $[XYZ]_B$, ... are the statically indeterminate moment vectors in the bays A, B, ..., respectively.
- H, V are the "horizontal" and "vertical" thrusts in any bay, and are related to Y, Z by the equations $Y = h\,H$, $Z = d\,V$, where h, d are lengths representing the height and span of a bay.
- μ the reciprocal of the flexural stiffness of a frame member, i.e., the ratio of length to moment of inertia of cross-section.
- $j\,k\,l$ the co-ordinates about any panel point of the moment vector [XYZ]. Since X is a pure moment, j is always unity, positive or negative. Since Y, Z are the thrust moments corresponding to the thrusts H and V, k and l are the geometrical co-ordinates of the panel points relative to the axes H, V, subject to a possible reversal of sign, depending on the sign convention adopted for the end moments in the frame members.

TABLE I.—DETAILS OF THE CONSTRUCTION OF A, A'_m, AND A'_n.

$$
A = \begin{array}{r} A_{m1} \\ n1 \\ m2 \\ .. \\ B_{m1} \\ n1 \\ m2 \\ .. \\ C_{m1} \\ n1 \\ m2 \\ .. \\ .. \end{array}
\begin{bmatrix}
j & k & l & . & . & . & . & . & . \\
j & k & l & . & . & . & . & . & . \\
j & k & l & . & . & . & . & . & . \\
\cdots & \cdots & \cdots & & & & & & \\
j & k & l & j' & k' & l' & . & . & . \\
j & k & l & j' & k' & l' & . & . & . \\
. & . & . & j' & k' & l' & . & . & . \\
 & & & \cdots & \cdots & \cdots & & & \\
. & . & . & j' & k' & l' & j'' & k'' & l'' \\
. & . & . & j' & k' & l' & j'' & k'' & l'' \\
. & . & . & . & . & . & j'' & k'' & l'' \\
 & & & & & & \cdots & \cdots & \cdots \\
. & . & . & . & . & . & j'' & k'' & l''
\end{bmatrix}
$$

$$
\begin{array}{l}
A'_m = \begin{array}{ccccccccccccc} A_{m1} & m2 & m3 & \ldots & B_{m1} & m2 & m3 & \ldots & C_{m1} & m2 & m3 & \ldots & .. \end{array} \\
\begin{bmatrix}
j & j & j & \ldots & j & . & . & & . & . & . & & . \\
k & k & k & \ldots & k & . & . & & . & . & . & & . \\
l & l & l & \ldots & l & . & . & & . & . & . & & . \\
. & . & . & & j' & j' & j' & \ldots & j' & . & . & & . \\
. & . & . & & k' & k' & k' & \ldots & k' & . & . & & . \\
. & . & . & & l' & l' & l' & \ldots & l' & . & . & & . \\
. & . & . & & . & . & . & & j'' & j'' & j'' & \ldots & j'' \\
. & . & . & & . & . & . & & k'' & k'' & k'' & \ldots & k'' \\
. & . & . & & . & . & . & & l'' & l'' & l'' & \ldots & l''
\end{bmatrix} \\
A'_n = \begin{array}{ccccccccccccc} A_{n1} & n2 & n3 & \ldots & B_{n1} & n2 & n3 & \ldots & C_{n1} & n2 & n3 & \ldots & .. \end{array}
\end{array}
$$

TABLE II.—DETAILS OF THE CONSTRUCTION OF B.

$$
B = \begin{bmatrix}
(2\,j_{m1} + j_{n1})\,\mu_1, & (j_{m1} + 2\,j_{n1})\,\mu_1, & (2\,j_{m2} + j_{n2})\,\mu_2, & \ldots \\
(2\,k_{m1} + k_{n1})\,\mu_1, & (k_{m1} + 2\,k_{n1})\,\mu_1, & (2\,k_{m2} + k_{n2})\,\mu_2, & \ldots \\
(2\,l_{m1} + l_{n1})\,\mu_1, & (l_{m1} + 2\,l_{n1})\,\mu_1, & (2\,l_{m2} + l_{n2})\,\mu_2, & \ldots \\
. & . & . & \ldots
\end{bmatrix}
$$

which shows the left-hand top corner of the matrix shown more fully below.

$$
\begin{array}{l}
B = \begin{array}{ccccccccccccc} A_{m1} & n1 & m2 & \ldots & B_{m1} & n1 & m2 & \ldots & C_{m1} & n1 & n2 & \ldots & .. \end{array} \\
\begin{bmatrix}
x & x & x & \ldots & x & x & . & & . & . & . & & . \\
y & y & y & \ldots & y & y & . & & . & . & . & & . \\
z & z & z & \ldots & z & z & . & & . & . & . & & . \\
. & . & . & & x' & x' & x' & \ldots & x' & x' & . & & . \\
. & . & . & & y' & y' & y' & \ldots & y' & y' & . & & . \\
. & . & . & & z' & z' & z' & \ldots & z' & z' & . & & . \\
. & . & . & & . & . & . & & x'' & x'' & x'' & \ldots & x'' \\
. & . & . & & . & . & . & & y'' & y'' & y'' & \ldots & y'' \\
. & . & . & & . & . & . & & z'' & z'' & z'' & \ldots & z''
\end{bmatrix}
\end{array}
$$

The matrix notation generally follows that used by Turnbull, but, since the algebra is always directed to the solution of the problem under discussion, the notation is less formal than would be necessary in a

The convention of sign for bending moments and fixing moments is that, in the arch members, a positive moment is that corresponding to a centre of curvature above the arch. For all the pillars, the positive moments correspond to a centre of curvature on the left-hand side. Thus the moments in the second pillar from the left are defined in relation to the second bay, and the action of the first-moment vector on this pillar involves a reversal of sign in forming the co-ordinates jkl from the geometrical co-ordinates of the panel points.

The method of enumerating frame members is shown in Fig. 1, and the directions in which the various moments and thrusts are normally taken as positive are shown in Figs. 2, 3, 4 and 5, on page 772.

The geometrical description of the frame is based on the points of intersection of frame members, or panel points, the positions of which are denoted by Cartesian co-ordinates z, y, with origin at the foot of the left-hand column in each bay.

The origin of the thrust axes H, V is the point z_0, y_0; V is taken parallel to the y axis and H inclined at an angle α to the z axis.

The strain energy in any member of the framework is

$$\delta U = \mu\,(m^2 + m\,n + n^2) + C \quad . \quad . \quad (1)$$

where C is independent of m and n, and m, n are related to the unknown end moments and the known fixing moments by the equations

$$M = m + F, \quad N = n + G. \quad . \quad (2)$$

The total strain energy for the whole framework is

$$U = \Sigma\,\mu\,(m^2 + m\,n + n^2) + \text{Const.} \quad . \quad (3)$$

where the summation includes every member of the frame.

There are two equations of statical equilibrium for each member of the framework:—

$$\left.\begin{array}{l} M = (j \mid X)_m + (j' \mid X')_m + S_m \\ N = (j \mid X)_n + (j' \mid X')_n + S_n \end{array}\right\}, \quad . \quad (4)$$

where

$$(j \mid X) = [j\,k\,l]\,\{XYZ\} = j\,X + k\,Y + l\,Z,$$

and the suffixes m, n distinguish the values of the coefficients at the two ends of the frame member. $\{XYZ\}$ and $\{X'Y'Z'\}$ are the two unknown vectors which act on the member under consideration.

For a framework of R members, there are 2 R equations of equilibrium, of the form (4), which may be written

$$\{M, N\} = A\,\{X\} + \{S_m, S_n\}, \quad . \quad (5)$$

where A is the complete coordinate matrix of 2 R rows and 3 N columns, if N is the number of bays in the framework and hence the number of unknown vectors. In this matrix, all the rows which relate to arch members of the framework have only three elements, and each row which is related to a pillar has not more than six.

Now introducing, in (5), the variables m, n for M, N,

$$A\,\{X\} - \{m, n\} - \{F, G\} + \{S_m, S_n\} = 0,$$

or

$$A\,\{X\} - \{m, n\} - \{f, g\} = 0. \quad . \quad (6)$$

Anticipating the requirements of the following paragraph, equation (6) may be written

$$(A_m + A_n)\,\{X\} - \{m, n\} - \{f, g\} = 0, \quad (6a)$$

where A_m derives from the 1st of equations (4) and A_n derives from the 2nd of equations (4) so that the elements of A_m only occur in equations involving m and f and that the elements of A_n only occur in equations involving n and g.

There are 3 N equations of minimum strain energy

$$\frac{dU}{dX_A} = \frac{dU}{dY_A} = \frac{dU}{dZ_A} = \frac{dU}{dX_B} \ldots = 0, \quad . \quad (7)$$

which may be consolidated in the form

$$\frac{dU}{d\{X\}} = 0. \quad . \quad . \quad . \quad (8)$$

Since U, as defined by equation (3), is a function of m and n,

$$\frac{dU}{d\{X\}} = \frac{dm}{d\{X\}}\frac{\partial U}{\partial m} + \frac{dn}{d\{X\}}\frac{\partial U}{\partial n}. \quad . \quad (9)$$

In this equation, the prior operator in the term on the right-hand side is $\dfrac{d}{d\{X\}}$, because it controls the number of single equations involved. Then, from equations (3), (8) and (9),

$$0 = \frac{dU}{d\{X\}} = \Sigma\,\frac{dm}{d\{X\}}\,\mu\,(2\,m + n) + \Sigma\,\frac{dn}{d\{X\}}\,\mu\,(2\,n + m) \quad . \quad . \quad . \quad . \quad (10)$$

where the terms covered by summation represent the contribution of any one member of the framework.

* "The Brabazon Assembly Hall at Filton," by C. B. H. Colquhoun. *Jl. Inst. C.E.*, March, 1949.

† "The Design of Structures," by H. L. Cox. *Proc. Sixth International Congress for Applied Mechanics*, 1947.

Now considering only one of these equations, i.e., by writing X for $\{X\}$ in (10), the terms on the right-hand side are of the form $(j \mid \mu \mid m)$, which is the matrix product $[j]\ [\mu]\ \{m\}$, where $[\mu]$ is the diagonal matrix of the flexural stiffness coefficients.

Hence, equation (10) may be written

$$\frac{d\{m\}}{d\{X\}} \cdot [\mu]\{2m+n\} + \frac{d\{n\}}{d\{X\}}[\mu]\{m+2n\} = 0. \quad (11)$$

Now from equation (6a)

$$\frac{d\{m\}}{d\{X\}} = \frac{d}{d\{X\}} A_m\{X\} = A'_m$$

$$\frac{d\{n\}}{d\{X\}} = \frac{d}{d\{X\}} A_n\{X\} = A'_n,$$

where A'_m and A'_n are the conjugates of A_m, A_n.

The strain-energy equations (8) now become

$$A'_m\ [\mu]\ \{2m+n\} + A'_n\ [\mu]\ \{m+2n\} = 0,$$

i.e.

$$(2A'_m + A'_n)\ [\mu]\ \{m\} + (A'_m + 2A'_n)\ [\mu]\ \{n\} = 0,$$

or

$$B\{m, n\} = 0. \quad . \quad . \quad . \quad (12)$$

where B is the matrix of $3N$ rows and 2 R columns, in which the 1st, 3rd, . . . columns form the matrix $(2A'_m + A'_n)\ [\mu]$, the 2nd, 4th, . . . columns form the matrix $(A'_m + 2A'_n)\ [\mu]$.

The equilibrium equations (6) and the equations of minimum strain-energy (12) have been found in the form

$$A\{X\} - \{m, n\} - \{f, g\} = 0$$
$$B\{m, n\} \qquad\qquad = 0.$$

Eliminating $\{m, n\}$

$$BA\{X\} = B\{f, g\},$$

or

$$Q\{X\} = B\{f, g\}, \quad . \quad . \quad (13)$$

in which the operational matrix $Q = BA$ is a square matrix of order $3N$, formed by the product BA, where A is a matrix of 2 R rows and $3N$ columns, and B is a matrix of $3N$ rows and 2 R columns.

The derivation of a practicable solution of equation (13) depends on the possibility of formation of the reciprocal matrix Q^{-1}, and the method, as already outlined, depends mainly on finding the operational matrix in the simplest possible form before attempting its inversion.

Details of the matrices A, A'_m, A'_n and B, on which the construction of the operational matrix depends, are given in Tables I and II, on page 773.

In Tables I and II, the suffix numerals denote the number of the frame member in any bay; the relevant bay is denoted *A*, *B*, . . .; and the two ends of the frame members are distinguished by the suffixes *m*, *n*. The suffixes are written outside the matrix box, to avoid repetition in each column or row.

From the form of the matrices B and A, as displayed in Tables I and II, it is easily seen that the product BA, giving the operational matrix Q, can be expressed as follows :—

$$Q = \begin{bmatrix} [A^2] & [AB] & . & .\,. \\ [BA] & [B^2] & [BC] & .\,. \\ . & [CB] & [C^2] & .\,. \\ . & , & .\,. & .\,. \end{bmatrix}. \quad (14)$$

where the symbols A, B, now refer to the bays of the framework *A*, *B*, and not the matrices of equation (13). In this notation

$$[A^2] = \begin{bmatrix} A^2a_1 & A^2a_2 & A^2a_3 \\ A^2b_1 & A^2b_2 & A^2b_3 \\ A^2c_1 & A^2c_2 & A^2c_3 \end{bmatrix}. \quad (15)$$

Here the symbols A^2, A B . . . are retained in designating the elements of $[A^2]$, [A B], . . ., since all the elements of $[A^2]$ are formed exclusively from the co-ordinates of the members of bay A, and [A B] depends only on the coordinates of the member common to bays A and B.

The elements of $[A^2]$ can be written down from the Tables thus,

$$A^2a_1 = \Sigma\,(2j_{m1} + j_{n1})\,j_{m1}\,\mu_1 + \Sigma\,(j_{m1} + 2j_{n1})\,j_{n1}\,\mu_1, \quad . \quad . \quad . \quad (16)$$

where the summations include all members of bay A, including the right-hand pillar. There are similar expressions for A^2b_2 and A^2c_3 in which j is replaced by k and l, respectively. The non-diagonal elements of $[A^2]$ give three pairs of equations represented by

$$\left.\begin{aligned} A^2a_2 &= \Sigma\,(2j_{m1} + j_{n1})\,k_{m1}\mu_1 + \Sigma\,(j_{m1} + 2j_{n1})\,k_{n1}\,\mu_1 \\ A^2b_1 &= \Sigma\,(2k_{m1} + k_{n1})\,j_{m1}\,\mu_1 + \Sigma\,(k_{m1} + 2k_{n1})\,j_{n1}\,\mu_1 \end{aligned}\right\} \quad . \quad . \quad . \quad (17)$$

similarly summed for all members of bay A.

Equations (17) show at once that A^2a_2 and A^2b_1 are identically equal, so that only three equations have to be solved to eliminate all the non-diagonal elements of $[A^2]$. Equations (16) and (17) show that the coefficients, *j*, *k*, *l* always occur as products. It follows that where both coefficients *k*, *l* have the opposite sign to the space co-ordinates from which they are formed, the sign of the product is not reversed. Each product is related to a particular member of the frame and the moments at the two ends of a frame member never reverse in sign independently. The only reversal in sign occurs when the sense of both M and N is reversed in the right-hand pillar of a bay. It follows that in forming the elements of the diagonal sub-matrices $[A^2]$, $[B^2]$, . . . of the operational matrix Q, the coefficients *k*, *l* can be replaced by the space co-ordinates and *j* can be taken as positive unity.

The two co-ordinates of the origin of the thrust axes and the angle of orientation of one of the axes give three disposable parameters for the elimination of *k* and *l* and the product *k l* in equations (17) and the corresponding equations. If z_0, y_0 is the origin of the thrust axes, and the inclination of H to the *z* axis is α, as in Fig. 5,

$$\left.\begin{aligned} k &= (y - y_0) + (z - z_0)\tan\alpha \\ l &= (z - z_0)\sec\alpha \end{aligned}\right\} \quad . \quad . \quad (18)$$

In writing down the equation for the elimination of A^2a_2, A^2b_1, etc., it is convenient to enumerate the panel points serially. Thus, suffix 1 designates the fixed end of frame member 1, and suffix 2 the intersection point of members 1 and 2. Equations (17) give

$$0 = 3k_1\mu_1 + 3k_2(\mu_1 + \mu_2) + 3k_3(\mu_2 + \mu_3) + \ldots$$

i.e.,

$$0 = \Sigma\,(y_r + z_r\tan\alpha)\,(\mu_{r-1} + \mu_r) - 2\,(y_0 + z_0\tan\alpha)\,\Sigma\,\mu \quad . \quad . \quad . \quad (19)$$

The corresponding equation involving *j*, *l* gives

$$0 = \Sigma\,z_r\,(\mu_{r-1} + \mu_r) - 2\,z_0\,\Sigma\,\mu, \quad . \quad (20)$$

and the third equation involving *k*, *l* gives

$$0 = \Sigma\,\mu_1\,(k_1 + k_2)\,(l_1 + l_2) + \Sigma\,\mu_1\,(k_1 l_1 + k_2 l_2), \quad . \quad . \quad . \quad (21)$$

where *k* and *l* can be expressed in terms of z_0, y_0, and tan α.

Equation (20) gives z_0 at once, and y_0 can then be found in terms of tan α by substituting in (19). Then z_0 and y_0 can be eliminated from equation (21), which becomes a bi-quadratic in tan α, and from which α can be found. The algebraic solution of these equations is not pursued farther, because there is no special difficulty in obtaining the arithmetical solution for a particular problem. For a symmetrical bay, in which the left-hand half is identical with the right-hand half, both in geometry and stiffness, $\alpha = 0$, that is, the axes H, V are orthogonal and parallel to the axes *z*, *y*. In this case

$$\left.\begin{aligned} z_0 &= \frac{d}{2} \\ y_0 &= \frac{\Sigma\,y_r\,(\mu_{r-1} + \mu_r)}{2\,\Sigma\,\mu} \end{aligned}\right\} \quad . \quad . \quad (22)$$

The elimination of the non-diagonal elements in the sub-matrices $[A^2]$, $[B^2]$, . . . of Q in equation (14), by the proper choice of thrust axes in each bay, makes it possible to reduce these sub-matrices to unity and to adjust the other sub-matrices accordingly, by simple multiplication instead of by matrix inversion and matrix multiplication. There is now a reduced operational matrix, defined by

$$Q_1 = DQ = \begin{bmatrix} I & [a^2b] & . & \ldots \\ [b^2a] & I & [b^2c] & \ldots \\ . & [c^2b] & I & \ldots \\ \ldots & \ldots & \ldots & \ldots \end{bmatrix}. \quad (23)$$

where D is the diagonal matrix of the reciprocals of the scalar elements of the leading diagonal of Q. The notation, as in equations (14) and (15), reflects the contribution of each bay of the framework to the formation of Q.

In this reduced form, the operational matrix can be inverted by the methods of Appendix I. An illustration of the formal method of inversion is fully detailed below, in the numerical solution of a symmetrical two-bay framework.

The statement of the problem has been found in matrix notation in equation (13), in the form

$$Q\{X\} = B\{f, g\},$$

Multiplying by D

$$DQ\{X\} = DB\{f, g\}.$$

Hence, from (23)

$$\{X\} = Q_1^{-1}DB\{f, g\}.$$

Now, writing Φ for $Q_1^{-1}DB$, and expressing f, g in terms of the end fixing moments and the panel-point moments due to the applied forces, the solution is

$$\{X\} = \Phi\{F, G\} - \Phi\{S_m, S_n\}, \quad . \quad (24)$$

which is the complete solution for the statically indeterminate quantities $[XYZ]_A$, $[XYZ]_B$, . . . in terms of moments which are obtainable directly from the particulars of the applied forces.

The solution matrix Φ contains only the geometrical and structural data of the framework, so that, for any framework, there is a structural solution which is independent of the details of the applied loading. An important application in structural design is that there will be a related family of solutions for a family of related frameworks, so that, when a range of solutions has been put on record, intermediate results will be available by interpolation.

It is of interest to note that, since $Q = BA$, $\Phi = (BA)^{-1}B$. Hence,

$$\Phi A = Q^{-1}Q = I. \quad . \quad . \quad (25)$$

The solution can therefore be completely checked by forming the product ΦA, in which the leading diagonal should approach unity, and all other elements should approach zero, within the limits of numerical accuracy required. For, though there are many values of Φ which satisfy equation (25), since A is a rectangular matrix in which the number of columns must always be greater than the number of rows, the probability of an inaccurate solution giving the unit matrix is too remote.

The moments at the ends of the frame members were found in equation (5) in the form

$$\{M, N\} = A\{X\} + \{S_m, S_n\}.$$

Inserting the solution for $\{X\}$ from equation (24),

$$\{M, N\} = A\Phi\{F, G\} - A\Phi\{S_m, S_n\} + \{S_m, S_n\}$$

or

$$\{M, N\} = A\Phi\{F, G\} + (I - A\Phi)\{S_m, S_n\}, \quad (26)$$

which gives the solution for the end moments in all the frame members, in terms only of the moments of the applied forces and a matrix product which contains only the geometrical and structural data of the framework.

The final operation is to express S_m and S_n in the form

$$\{S_m, S_n\} = [s', t, p]\{S', T, P\}, \quad . \quad (27)$$

where [S', T, P] is the applied load vector at any point, taken as pure moment and horizontal and vertical force components, with the relevant geometrical co-ordinates *s'*, *t*, *p*. No further interpretation of equation (27) is given, since its effect will be obvious in a numerical example.

(*To be continued.*)

WIND POWER IN NORTHERN IRELAND.—The potentialities of generating electricity by wind power in Northern Ireland are being examined by means of experimental plant which has been erected on Divis Mountain, overlooking Belfast; in the Mourne Mountains, County Down; in the Sperrin Mountains, County Tyrone; at a site in County Antrim; and at Slieve Gullion, County Armagh.

NEW ADDITIVE FOR AVIATION PETROL.—The Shell Petroleum Company, Limited, have developed a new additive, tricresyl phosphate, for aviation petrol, which modifies the deposits formed in the cylinders, rendering them electrically non-conductive and non-corrosive to the valve material and thus eliminating the fouling of sparking plugs and reducing the risk of exhaust-valve failure. After a prolonged period of testing by the engine manufacturers, flight tests of the new additive have been carried out in the United States. The British Overseas Airways Corporation will also be carrying out extensive flight trials under normal commercial operating conditions.

CONCRETE STRUCTURES AND CORROSION.

By Leslie H. Griffiths, M.Sc., F.R.I.C.

During the past two or three decades, reinforced concrete has made great strides as a constructional medium. Because it lends itself so readily to design and fabrication, it has brought new possibilities and entirely new techniques into structural engineering, and the rapid developments of prestressing methods are extending its applications into yet other fields. This greatly expanded and varied use of concrete has imposed corresponding demands on the specialist engaged on the prevention of industrial corrosion, who is being asked, in many new circumstances, to provide protection against corrosive attack so that full advantage may be taken of the flexibility in fabrication of reinforced concrete. In this general survey of the problems involved and the methods employed in anti-corrosion work, the writer has chiefly in mind tanks, effluent conduits, processing chambers and similar units, in actual contact with chemical liquids, rather than with large structures. It can be said, however, that where these latter are subjected to vapourous corrosive attack, some at least of the points will be applicable, and indicative of the lines along which anti-corrosion research is proceeding.

Tanks—a word which can be used conveniently to describe a variety of concrete structures intended to store or carry liquids—present, in some ways, the most difficult of these problems. Concrete has little tensile strength and any settlement, or even unduly violent expansion movement, will produce cracking; this may not be serious from a structural point of view, but it is important to the anti-corrosion specialist, whose applications are not intended to have structural strength and, therefore, will certainly crack also, leaving the way open for permeation of the concrete by corrosive liquors. In the larger tanks, expansion joints can be a source of trouble and, in designing the protective treatment, it is necessary to take into account the relative degree of movement of the jointing and the corrosion-resistant lining; often this is by no means easy, since, perhaps, the material preferred for the specific chemical conditions may have insufficient elasticity to move with the joint.

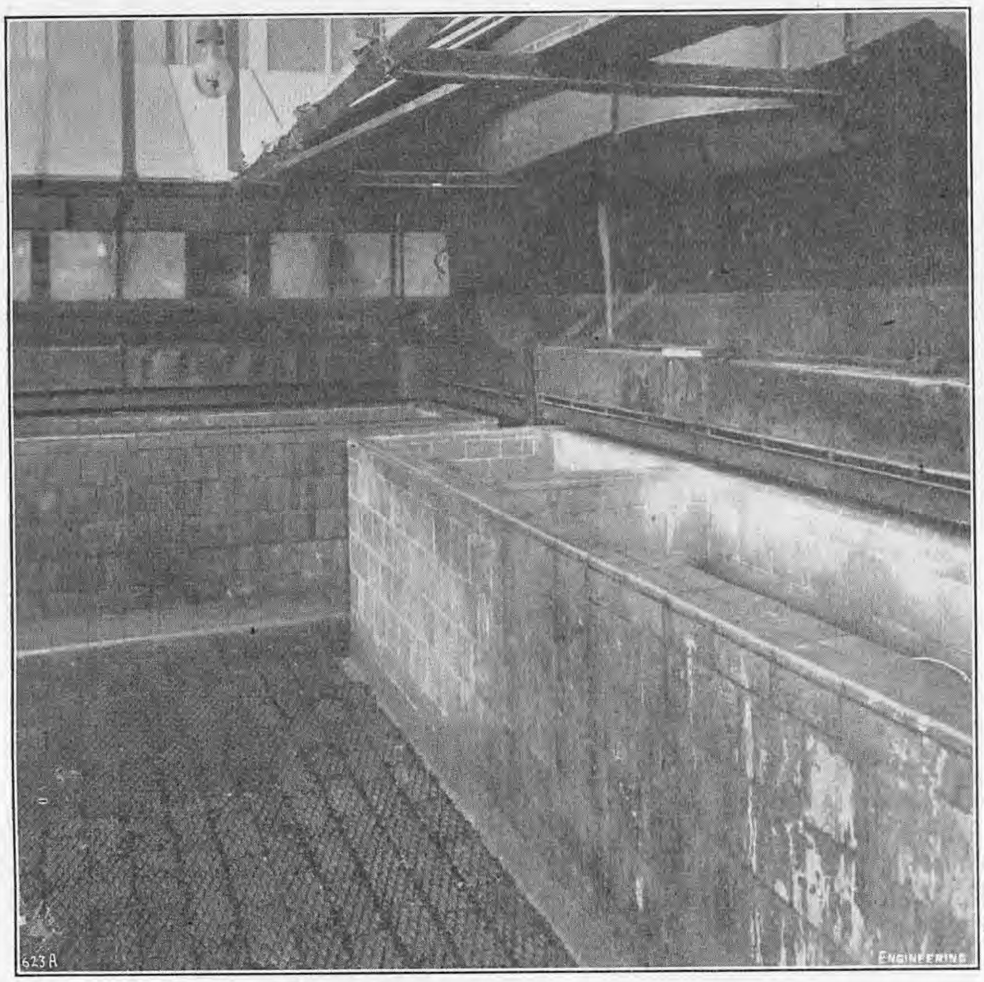


Fig. 1. Hydrochloric-Acid Tanks of Protected Concrete.

Fig. 2. Concrete Floor Protected Against Acid.

A further complication is that of external water-pressure, in the case of tanks constructed partly or wholly below the surface of the ground. Seepage of surface water, which breaks or prevents the complete seal between the protective lining and the internal walls of the tanks, frequently presents a bigger problem than the provision of an efficient protective treatment. It is customary to use a bituminous material, and a good coating is required to cover the entire external walls of the tank. Furthermore, a damp-course must be arranged under the tank, so that the whole of the outer skin is protected. More elaborate precautions are required where the level of the water table rises above the base of the tank. Various asphalting techniques are used under these conditions. The spray application of hot asphalt by means of a "flame gun" is a comparatively new method, with which some success has been obtained.

Fig. 1, herewith, shows, as an example, some concrete immersion tanks to hold concentrated hydrochloric acid. They are lined internally with rubber and then completely tiled on all faces with acid-resistant tiles set in a silicate cement. The screeded concrete floor is covered with acid-resistant paving, bonded to the screed with a latex-cement mixture and jointed with synthetic-resin compound. The fume-extractor ducting above the tanks is treated with a rubber-resin coating, applied *in situ*, as a protection against attack by the corrosive vapour.

Before discussing the actual anti-corrosion treatments, one other point must be dealt with in regard to construction, namely, the importance of the finish of the cast concrete. To avoid surface friction and to facilitate flow as much as possible, the internal walls of the tank must be free of irregularities. Notwithstanding the continuous improvement in shuttering methods, it is seldom that cast concrete provides a perfectly smooth and true overall surface upon removal of the formwork. This involves making good or "facing up," and it is important that this should be efficiently done, as any failure, leading to breakdown of the anti-corrosion treatment, will prove costly.

For this purpose, rendering with a normal cement and sand composition is often specified, but it is not always wholly satisfactory. Sprayed cement, subsequently faced up, has been used, but, in the writer's experience, some of the best results are obtained by the use of a compound of Portland cement, good washed sand and natural rubber latex. Before the war, rubber latex was coming into use in the constructional industries for a variety of purposes, and, since 1945, it has become increasingly important, being used extensively for flooring work, for example, as well as in the allied field of anti-corrosive treatments. Its addition to a cement/sand composition gives to the compound remarkable adhesive properties, and it is possible to apply, with a trowel, renderings ranging from a paper-thin coat to any desired thickness. If necessary, a very fine surface can be obtained with an ordinary sanding machine.

With a view specifically to eliminating the risk of failure of adhesion, and also the costly and laborious hacking usually necessary when applying a rendering coat to existing concrete, a series of compounds based on synthetic-resin emulsions has been developed recently. These bond coats are very effective and it has been found possible, by their use, to cut down the thickness of normal cement-sand renderings to the minimum necessary to secure a smooth and level surface.

In the protection of concrete tanks against chemical attack, it is unusual to encounter the same problem twice. The conditions are so diverse and can be so complex that, after a careful analysis of all the factors involved, a recommended treatment will probably represent a balance of several possibilities. It will be convenient to consider first the most simple treatment, for the milder conditions, before proceeding to the more complicated procedure required to withstand conditions of greater severity.

In addition to providing a smooth working base, the composition containing rubber latex and cement is an excellent chemically-resistant foundation upon which to build up the protective application. A normal thickness of $\frac{3}{16}$ in. is applied to the cast concrete as a rendering, and is allowed to set hard. For relatively mild conditions, it is often sufficient to apply over this rendering a paint coat of synthetic rubber—synthetic rubber being preferred to natural rubber because it is easier to apply as a solution. This treatment can be carried one stage farther; with proper care in selecting materials, it is possible to make up a solution of synthetic rubber (using aromatic solvents, for example), which, with a solid content of about 50 per cent., will be of a paste-like consistency. This paste is readily applied with a trowel and, in this way, synthetic-rubber linings can be built up, *in situ*, to a thickness of $\frac{1}{16}$ in. By adding suitable chemicals to the solution, the rubber can be vulcanised during the process of drying out.

Rubber applied in this form lacks the efficacy of sheet rubber, but, under limited conditions of chemical attack, it will function satisfactorily and, in these cases, affords a method of protection which is comparatively easy to execute and relatively inexpensive. An example of the use of this method is the lining of concrete petrol tanks. For the storage of petroleum, a concrete tank has much to commend it, and this method of providing the necessary chemically-resistant lining is undoubtedly one of the most economical. By using, in place of natural rubber, a synthetic latex which is oil-resistant, and by applying several coats, the latex-cement compound can be modified to dispense with the secondary surface treatment. Where faults are likely to develop under load, however, the combination of a natural latex-cement rendering and a synthetic solution sealer is always preferable, because of its better self-healing properties.

As a variant of a synthetic-rubber solution, partly condensed synthetic resins may be used as the basis of a coating which, applied over the base rendering of latex-cement, will withstand a higher degree of chemical attack. Coatings of this type require the addition of a chemical reagent to bring about the setting action. This is added to the compound immediately before the application and, upon setting, the coating forms a dense and impervious layer which has a tenacious grip on the base rendering coat. As the layer will resist both strong acids and alkaline attack (although not oxidising acids), the treatment is quite suitable where conditions are not so severe as to demand the more efficient, and more costly, methods of protection. Unfortunately, it cannot be used safely where contact with hot or boiling water is likely. It is a curious fact that cements which are immune to acidic attack quite often will not resist hot water. Fig. 2, on page 775, shows a concrete floor protected against spilling of acid by tiling set in a compound of rubber and resin cement.

Sheet rubber, one of the most common of the materials used in tank-lining work, has largely displaced lead, which, though chemically effective, is scarce, costly and undesirably heavy. For many years, it has been customary to use rubber linings to withstand mineral acids, except nitric and chromic acid. It is of prime importance, however, that the rubber manufacturer should be consulted in each case as to the concentration and temperature of the acids used, and the working conditions to which the linings are to be subjected, so as to ensure that the most suitable type of material is chosen.

Despite the steady development of plastics, natural-rubber linings are still probably the most versatile protective medium against the attack of corrosive liquids. The installation of them, however, is a task which demands considerable skill and experience. Great care must be taken, particularly if the tank is to contain liquids at raised temperatures, to exclude all air from beneath the rubber sheeting. The concrete must be dry, and a good smooth base is most important. For these reasons, a rendering of latex-cement compound, as previously described, is advantageous. Not only does this give a smooth and true surface, but the relationship between the solution used to fix the rubber sheeting and the latex in the rendering compound ensures a positive and permanent bond. To increase this bond strength as much as possible—a vital factor—chemicals are added to the adhesive solution to vulcanise the rubber content during setting. This process is exactly similar to the vulcanising of tyres, etc., to develop the toughest and strongest qualities of the rubber. The rubber tank linings are themselves vulcanised, of course, after installation.

Natural rubber is not normally used where the tank lining will come into contact with solvents or with certain other materials, such as coal tar, which will attack rubber even when present only in traces. A synthetic rubber might be used under these conditions. Though their cost is generally high, most of the synthetic rubbers have special properties which will often justify their use in particular circumstances. Also, though it is not a true rubber, polyvinyl chloride may be mentioned as a similar type of material, suitable for some purposes, as it resists grease and oil, and many solvents. It is used either as a rigid sheeting or in a plasticised form which gives the material a rubber-like flexibility. Synthetics of this type offer many technical advantages and their use is now well established, though it may not always be justifiable on a price basis. Their more extensive use will depend largely on the further developments in handling techniques, and proof of their reliability in service.

Sheet rubber or plastic linings are seldom left unprotected against physical damage. Usually, the linings are themselves protected by an inner lining, invariably of brickwork. Where periodical cleaning is necessary inside the tank, or if plant process operations are such that heavy units are immersed in the tank's contents, the possibilities of irreparable damage to unprotected rubber are obvious. Even if little likelihood exists of physical damage, brick linings are built where the tank is to contain hot liquors. The greater the temperature, the faster is the chemical attack, and it is useful, therefore, to keep as cool as possible the liquids in contact with the rubber. The thicker the brick lining, the better is the insulation.

The thickness of a brick lining will be determined by operating conditions. If the brickwork is intended only to protect the rubber membrane from physical damage, a $4\frac{1}{2}$-in. wall may be sufficient. If, on the other hand, insulation is a primary factor, 9 in. may be specified. The function of the brickwork being simply to protect the anti-corrosion membrane from damage, firm bonding of the brickwork to the membrane is not always necessary or desirable. This poses a difficult problem, particularly with large tanks or with those containing liquors at elevated temperatures, namely, that of allowing for the differing expansion coefficients of the brick lining and the tank walls. Owing to the temperature gradient between the face of the brickwork (in contact with the hot liquids) and the back of the anti-corrosion membrane, the concrete walls of the tank will be subjected to much less rapid changes of temperature than the brick lining. The corresponding time lag in expansion and contraction movements may lead to distortion and cracking of

PROTECTION OF CONCRETE AGAINST CORROSION.

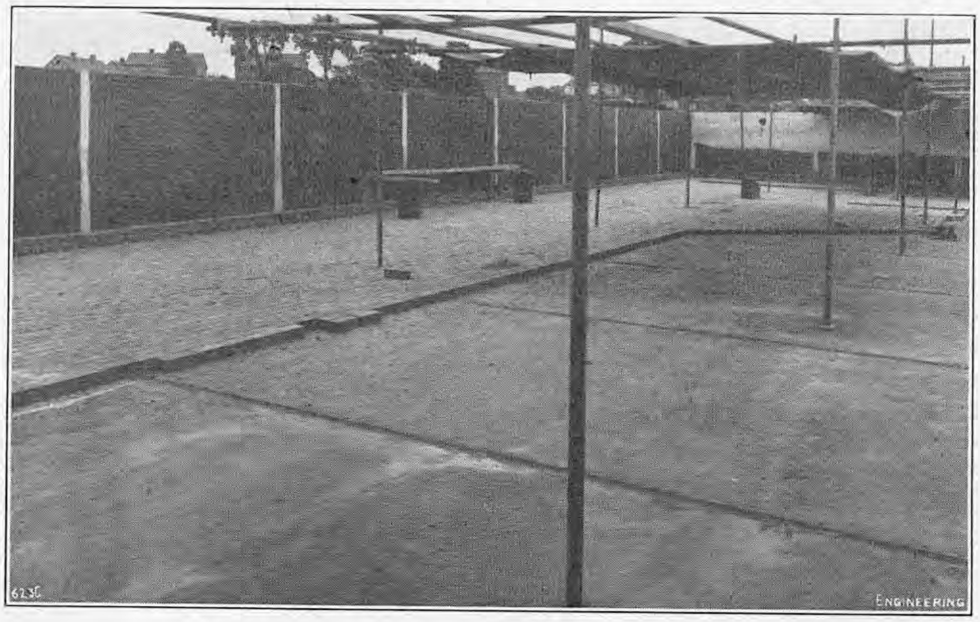


Fig. 3. Anti-Corrosion Linings in Effluent Tank.

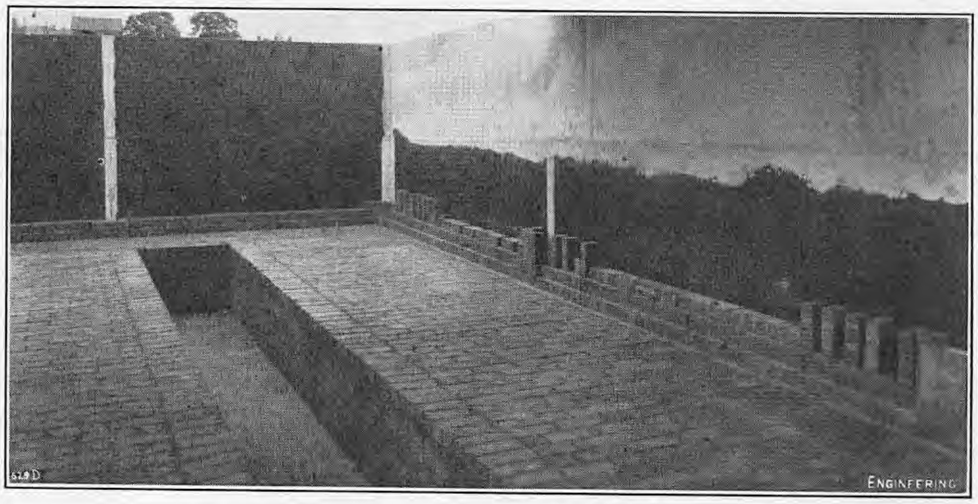


Fig. 4. Sump and Part of Tank Floor Completed.

the brickwork, unless an adequate safeguard is provided.

It is of the first importance to use a suitable cement as a bedding and jointing medium when constructing brickwork forming part of any chemical-resisting treatment. Several types are available, all with particular properties and capable of giving high performance under specific conditions. In the past, much work has been done with a cement based on sodium silicate and silica flour, the two materials being caused to react by the addition of sodium silico-fluoride. While this possesses good acid-resisting qualities, however, it is very brittle and inexpansible. It is also comparatively freely leached out by water. A cement based on a compound of natural rubber latex and aluminous cement has mild acid-resisting properties, and alkali resistance up to 4 per cent. of caustic alkali. It gives excellent results under conditions of alternating acidic and alkaline attack. Possibly its greatest value lies in its adhesive strength and in its inherent flexibility, which is sufficient to take up some expansion and contraction movement.

Figs. 3 and 4, opposite, illustrate a typical example of anti-corrosion lining in an effluent tank, Fig. 3 showing a general view and Fig. 4 the sump (visible in the background of Fig. 3) and a completed section of the floor. The rendering of the walls is in progress and the lowest courses have been laid of the brick lining of the walls. The corrosion-resistant membrane completely covers the floor and walls, and the brick linings are built in chemically-resistant cement.

Many of the newer synthetic resins have been used as the basis of chemical-resisting cements, and those based upon the phenolic and furane groups of resins are probably capable of giving the most efficient results in present-day construction. Resin cements of this type are costly, but they will withstand the action of acid at high concentrations and of alkali at moderate concentrations, and they are invaluable in providing protective applications in some of the modern complex operations of industrial plants. They have the disadvantages, however, of not being resistant to strong oxidising acids.

Though the erection of this type of brickwork differs little from ordinary bricklaying practice, the special cements employed in anti-corrosion work handle differently and behave in a very different manner from conventional cement-sand mortars. The risk of costly failure cannot be taken, and, therefore, the construction of chemical-resisting brickwork is always entrusted to contractors who have specialised knowledge of the cements and experience in their application.

More and more the services of the corrosion engineer are being sought for the protection of buildings. Many of the lessons learned in shielding processing chambers from the corrosive attack of liquids can be applied in devising methods for protecting structural concrete exposed to vapourous or gaseous attack. It is not generally necessary to attempt actual encasement of structural members; the ideal, in fact, is a simple paint coat, easy to apply and inexpensive to provide. Unfortunately, it is far from easy to formulate a paint which is at once cheap and effective. Few of the ordinary paints will give efficient protection over concrete, and it is necessary to produce in paint form materials known to have suitable anti-corrosion properties. Of these, chlorinated rubber, which is immune to alkaline attack and has a good resistance to many other forms of chemical attack, has been successfully used as the basis of a paint. Vinyl resins, popular also for their immunity to alkaline attack and general effectiveness, are yielding a series of paints specially adapted for application to concrete surfaces and giving good results under a variety of conditions.

Synthetic resins offer, perhaps, the most interesting possibilities of development in this field, and considerable advances have been made in their use during recent years. A latex, or water-emulsion, of synthetic resin has the advantage of being free from inflammable solvents and is thus readily usable under all industrial conditions. A typical composite treatment consists of a priming coat made by mixing cement with the latex, a trowel coat composed of latex filled with a fibrous material such as asbestos fibre, and a brush-finishing coat of undiluted latex. This gives a coating of resistant material about $\frac{3}{16}$ in. thick, which, by reason of its multiple nature, is free from cracks and pin-holes. The whole process being carried out at room temperature, it becomes possible to undertake *in situ* protection of towers and similar industrial structures. This means of coating with emulsion is feasible, requiring only careful choice of the correct synthetic emulsion. The difficulties generally encountered are practical rather than chemical.

A more novel method, as yet largely experimental, of using these highly-resistant synthetic resins employs glass cloth as a carrier or reinforcing agent. Over a priming coat (of chlorinated rubber paint) a layer of glass cloth is applied, a further application of chlorinated rubber solution being used as an adhesive to bind the glass firmly to the priming. To this open-weave base, resin cement is applied, filling the interstices and covering the whole surface until a smooth and continuous hard layer has been built up. More than one layer of glass cloth may be used where conditions of chemical attack are particularly severe. The alkaline nature of concrete prohibits the direct application of those synthetic resins which are acid-hardened. The use of a suitable primer overcomes this difficulty, and the glass-cloth membrane gives strength and robustness to the coating by affording a physical reinforcement.

The hope of finding effective answers to many of the new and complex problems now arising lies largely with the synthetics industry. Post-war difficulties have handicapped that industry in many ways, but the technical development of a variety of promising new materials has been pushed forward. The technique of adapting these new products to such purposes has to be learned by the anti-corrosion specialist, who is in no position to risk using untried specifications; but one example, polyethylene, will suffice to show that the possibilities of synthetics are being investigated energetically as they become available. Polyethylene, one of the most chemically resistant plastics, can be prepared in sheet form and welded up quite simply. A method is already being tried of lining liquid containers with a loose bag or envelope of fabricated polyethylene sheet. For the protection of structural concrete, experiments have been made in spraying the plastic in powder form by means of the so-called "flame gun." There is no doubt that, given access to the new materials developed by the synthetics industry, the specialist in problems of industrial corrosion will be able to keep pace with the growing demands.

SMITHFIELD SHOW AND AGRICULTURAL MACHINERY EXHIBITION.—According to a statement by the Smithfield Show Joint Committee, the total paid-attendance figure for this year's show was 65,903; this was 16,522 more than last year and is the largest number ever to attend the Show. The statement adds that, despite the outbreaks of foot-and-mouth disease, livestock was well represented and that in the trades section record orders amounting to a value of approximately 12,500,000*l*. were placed, more than half this total representing equipment for export.

INTERNAL COMMUNICATIONS AT THE ESSO REFINERY, FAWLEY.—The care which has to be exercised when installing ancillary equipment in oil refineries is, perhaps, exemplified by the fact that the internal-communications system installed at the Esso Petroleum Company's new refinery at Fawley includes a number of flameproof telephones and associated relays, bells, etc. The system comprises a 600-line private automatic telephone exchange which was designed and manufactured by the Automatic Telephone and Electric Company, Limited, Strowger Works, Liverpool, 7. The initial capacity of the exchange is 450 extensions, consisting of one group of 415 lines for general service and one group of 35 lines for general service and fire and accident reporting. To report a fire, the caller dials "0" and is connected automatically to the fire-control office, when he can either speak to the officer in charge or replace the receiver once the ringing tone is heard, a lamp indicator automatically showing the place from which the call was made. Simultaneously, the fire-control telephone is switched to a special selector train which gives priority over all other calls. Accident calls, originated by dialling "9", are identified and dealt with in a similar manner but the equipment is arranged to give overall priority to fire calls. The complete system was installed by Communication Systems, Limited, who will also be responsible for servicing arrangements.

THE IRON AND STEEL INSTITUTE.

(*Concluded from page 742.*)

WE conclude below our report of the Iron and Steel Institute's annual autumn meeting, held in London on November 21 and 22.

HIGH-PURITY IRON AND IRON ALLOYS.

The first part of the morning of November 22 was devoted to a joint discussion on two papers, namely, "The Production of High-Purity Iron and Iron Alloys on a 25-lb. Scale," by Mr. B. E. Hopkins, Mr. G. C. H. Jenkins, Mr. H. E. N. Stone and Mr. H. G. Short; and "Tensile and Impact Properties of Iron and Some Iron Alloys of High Purity," by Mr. W. P. Rees, Mr. B. E. Hopkins and Mr. H. R. Tipler. Both papers described research work conducted in the Metallurgy Division of the National Physical Laboratory, Teddington, Middlesex.

In the first of the two papers, which was presented by Mr. B. E. Hopkins, the authors described the method and equipment developed to produce iron and iron alloys of high purity in the form of 25-lb. ingots. They stated that, starting with a selected batch of Swedish iron supplied as 4-in. square billets $\frac{1}{2}$-in. round bars and 5-mm. strip, the purification procedure was carried out in the molten condition in two main stages. By melting the iron in air, the proportions of the readily oxidisable impurities present could be reduced to low values. The second stage comprised a vacuum treatment for degassing, followed by the reduction of oxygen to a low level by remelting in dried hydrogen. The carbon, silicon and chromium contents were decreased by the oxidation process and a limited success was achieved in reducing the sulphur content. The oxygen and nitrogen contents were reduced to low values by melting in hydrogen. The ingot mould mostly used was of mild steel and octagonal in cross section. Recently, a tapered mould of similar general design had been used. No dressing was applied to the mould surface.

In presenting the second of the two papers, Mr. W. P. Rees said that the authors had stated therein that the purest irons which had been prepared in the 25-lb. furnace were very ductile at room temperature and at −73 deg. C. when tested in simple tension, but became brittle on cooling to between −73 deg. C. and −196 deg. C. Fracture at −196 deg. C. took place by cleavage with less than 5 per cent. elongation, at a stress of about 45 tons per square inch. Iron prepared in the same manner, but containing more than 0·002 to 0·003 per cent. of oxygen, had properties very similar to those of high-purity iron in the ductile condition. When embrittled by cooling to −196 deg. C., the tensile strength was much lower, namely, 27-33 tons per square inch, and the fracture was partly inter-granular and partly cleavage. The transition temperature, in the Charpy impact test with an Izod V notch, which occurred at about −15 deg. C., for the purest irons, rose with increasing oxygen content, and the brittle fractures were again partly intergranular. The addition of up to 5 per cent. of manganese to pure iron increased the yield stress and tensile strength; at −196 deg. C. there was also an increase in ductility. Manganese, however, decreased the impact transition temperature. The addition of 0·01 per cent. of carbon to high-purity iron had very little effect on the tensile and impact properties of normalised material. Larger additions, up to 0·05 per cent., raised the impact transition temperature appreciably, without a large effect on the tensile properties. The addition of manganese to an iron containing 0·05 per cent. of carbon progressively lowered the impact transition temperature, which, in an alloy with 2 per cent. of manganese and 0·05 per cent. of carbon, was lower than in a simple 2 per cent. manganese alloy. Manganese and carbon together also lowered the transition temperature in tension.

Dr. M. L. Becker, who opened the discussion, stated that he would like to know why there was no mention in the paper of the name of the manufacturers or suppliers of the apparatus. The willing and even energetic co-operation of the manufacturers was essential, quite apart from questions of payment. Moreover, if the whole of the equipment was not supplied by outside contractors an indication should be given regarding which parts had to be made in the laboratory or in the laboratory workshops. The method of making additions to the melt, namely, the hanging of a small packet on the arm of the rod supporting the lid, seemed quite adequate for the relatively low-alloy contents required in the present work, but if larger and more numerous additions were necessary it was obvious that some alternative device would have to be incorporated. He was convinced that the type of equipment described in the paper would become very much more common, not only in the laboratory for research purposes, but also as production units, and for that reason alone the authors' views on such questions as he had raised should be worth recording in the *Journal*.

The second paper gave the first fruits of the main investigation, designed primarily to throw light upon the so-called, and much-talked-of, notch brittleness of mild steel. Probably the outstanding feature of the preliminary work was the sharp transition from tough to brittle fracture in the impact test. In the case of the pure-iron series of melts of which figures were given, the authors had shown clearly that oxygen played a very important role in determining the type of fracture either in the tensile or in the impact test. Apparently, they had shown that the presence of oxygen in excess of 0·002 per cent. or 0·003 per cent. rendered the iron liable to intergranular, as distinct from cleavage, fracture when broken below the transition temperature, — 196 deg. C., in these tests. From these results, it seemed that the conclusion was that oxygen—probably present as thin boundary films of FeO, though this was not known—was in some way bound up with the transition temperature itself, even when the content was below that required to promote an obvious intergranular brittle fracture. Looking at the other series of tests in the paper, there seemed to be nothing in the tests on the manganese or the manganese-carbon series which would contradict such an assumption.

Dr. N. P. Allen said that, in the pre-war period, the scale of production of the pure iron was about 6 lb., and Dr. W. H. Hatfield was very insistent that that scale of operations was not large enough. He said, "We want pure iron, and lots and lots of it." There was no doubt that he was right, because it was proved in practice that it was not possible to get much information about the mechanical properties of a metal from a few pounds of it. At the end of the war, therefore, when the subject had been taken up again, the scale chosen was 25 lb., which, if necessary, could be increased to 50 lb. or more. The next question was what standard of purity should be aimed at, and the standard of less than 0·01 per cent. of any impurity had been chosen because it was thought that this would be practicable.

There had been a great deal of thought among engineers along the lines that if the yield-point of structural steel could be raised, then it would be possible to save a great deal of steel, in practice, by reducing the sections of various girders and so on. There was a specification, B.S. No. 968, which dealt with steel of raised yield-point, and that required a yield-point of 23 tons per square inch. The yield-point of pure iron was about 5 or 6 tons per square inch, but if 0·04 per cent. of carbon were added, and nothing else whatever, and that carbon were in the right structural condition, the resultant material had a yield-point far above 23 tons per square inch. B.S. No. 968 allowed for 1·8 per cent. manganese and 1·0 per cent. chromium, with the condition that manganese plus chromium should not exceed 2 per cent. In addition, 0·5 per cent. nickel and 0·5 per cent. copper were permitted, and some steels of this class contained 0·1 per cent. or 0·2 per cent. of molybdenum as well. What were all these alloying elements doing? Apparently, they were getting the carbon into the right condition, but no one knew which of them was effective. The conclusion had been arrived at that almost the whole of the alloying elements could be saved if only a method of getting the metallographic condition needed with the requisite 0·04 per cent. carbon could be found.

Dr. W. Steven said that one of the more interesting features of the second paper was the susceptibility of occasional batches of the iron to intergranular embrittlement. The authors had presented ample evidence to demonstrate that this susceptibility depended on oxygen content; nevertheless, there were indications that there were other important variables. The authors, in discussing the carbon alloys, had referred to the reduction of aluminium from alumina crucibles. It would be interesting to know whether they had also detected traces of magnesium, or possibly of calcium, and had considered the possibility that the presence of these elements tended to neutralise the effect of oxygen. Magnesite linings were used for the first stage of the production of the iron, and, although alumina crucibles were used for the second stage, the authors mentioned that the crucibles cracked during the first melt, and that they relied on the backing of magnesite to prevent seepage. From work principally on cast iron it was fairly clear that magnesium could be reduced from magnesite at high temperatures from furnace linings, at least in amounts of the order of the oxygen content of these irons, and very likely in much higher amounts. Finally, he would emphasise that the type of embrittlement which was encountered in the N.P.L. iron might have little in common with the type of embrittlement encountered in commercial steels, and might be wholly characteristic of this very pure material.

Mr. B. E. Hopkins, replying to the discussion on both papers, said that, in his remarks on the second paper, Dr. Becker had stated that he thought there was some evidence of oxygen content affecting the transition temperature even when the oxygen was present in amounts smaller than would give rise to intergranular failure. He (Mr. Hopkins) did not agree with that. They had evidence, not given in the present paper, but which came from their study of iron-oxygen alloys, which showed that, for oxygen contents below that required to give intergranular failure, there was no difference in properties at all between a number of irons. There were about half a dozen with oxygen contents of less than 0·002 per cent., and they all gave about the same transition temperature and the tensile properties were much the same. Their view was that oxygen contents present in amounts less than would give intergranular brittleness did not seem to have much effect on the properties. Dr. Steven had mentioned that, when cast irons were melted, reduction of magnesium from a magnesite lining was possible. There was little doubt that material with a very high carbon content would cause a reduction, but their carbon contents were very low, and the magnesium and calcium contents of their irons were below the limits of analysis. Dr. Steven had said that the type of embrittlement obtained in N.P.L. iron might have little to do with the embrittlement obtained in commercial steels. There he disagreed flatly, because he thought that it had very much to do with it. He believed that this work, in due course, would give the answer to embrittlement in commercial steels, and the reason that it could not be got from an examination of commercial steels was that there was too much variation in the impurities present, and there were too many of them.

Properties of Segregates in Alloy Steels.

The third paper considered on Thursday morning, November 22, was by Dr. H. M. Finniston and Mr. T. D. Fearnehough, and dealt with "Physical and Mechanical Properties of Segregates in Two Alloy Steels." It was presented by Dr. Finniston. The authors stated that the use of large alloy-steel forgings for naval armaments had led the Bragg Laboratory of the Naval Ordnance Inspection Department, Sheffield, to investigate the metallurgical nature and characteristics of the segregates in two such forgings, made, respectively, from a 3·5 per cent. nickel steel and a 2·5 per cent. nickel-vanadium steel. It had been found that a difference in hardness between a segregate and the matrix persisted in all hardened and tempered samples, whatever the hardness level. The greater hardness of segregates by comparison with their adjacent matrices was reflected in their higher proof and maximum stresses. Their elongation and notched impact values were generally lower, and in some cases markedly so. There was a composition gradient across each segregate, rendering them more highly alloyed in nickel, vanadium and molybdenum than the adjacent matrix. Macrostructural differences across the width of segregates had also been observed, and the segregates contained more non-metallic inclusions than the adjacent matrix. Segregates appeared to be concentrated metal, and, when liquid, were entrapped between the main spines of solidifying dendrites which surrounded them. Metal in the interdendritic arms showed variations in hardness and composition comparable with those shown by segregates.

In the course of the discussion, Dr. W. Betteridge said that it was of much interest practically to understand both the chemical nature of the segregates observed in alloy steels and the differing mechanical properties of such segregates when the body of the steel was heat-treated. There appeared to be two main factors controlling the differences in mechanical properties of matrix and segregate, and these had been pointed out by the authors. There was first the differing chemical composition, which resulted in the segregate having transformation characteristics different from the matrix, and, secondly, the higher non-metallic inclusion content of the segregate. Of the various mechanical properties measured, however, the hardness was unique in being unlikely to be affected significantly by the inclusion content, so that it appeared reasonable to accept it as a measure of the changes in properties solely due to the differing composition, and therefore the differing hardenability, of the segregate. It appeared unfortunate, perhaps, that the authors had so far confined their attention to steels which were essentially chromium-free, for micro-radiographic work by various authors had indicated that chromium was particularly liable to segregate, and, in view of its strong effect on hardenability, could be expected to have a particularly marked influence on the mechanical properties of the segregates.

Mr. D. R. Thorneycroft said that the authors drew attention to the fact that there might be other methods of testing segregates, and had mentioned micro-radiography. It would be of interest to examine massive segregates by the micro-radiographic method to determine whether the nickel segregates were as pronounced as the spectrographic and micro-chemical tests suggested. In the field of micro-radiography, tests on nickel-containing steels had not provided marked evidence of nickel segregation, whereas chromium and manganese segregation had been clearly defined. Turning to the mechanical properties of the massive segregates, he could contribute further tensile-test data that had recently been obtained on aircraft forgings of 1½ per cent. Ni-Cr-Mo steel, measuring from 18 to 22 in. in diameter, which exhibited massive segregates towards the centre but not at the rim. The segregates were harder than the surrounding matrix, and were responsible for low ductility in the fully-hardened and tempered material at the centre of the forgings. The loss in ductility was greater at high levels of tensile strength above 80 tons per square inch, when the segregates, although stronger than the surrounding matrix, were less ductile, and fracture occurred preferentially through their brittle structure.

Mr. T. D. Fearnehough, in a brief reply, said that it was interesting to hear that transverse fracture occurred preferentially in segregates. When this paper had been presented privately in 1942, that question had been raised. The suggestion had now been made by several persons that this preferential fracture in the segregate might not be due merely to inclusions, but that the material itself might be inherently more brittle. It was also interesting to hear that fracture through the segregate might be reduced by tempering. From the naval ordnance point of view segregates were important, and this consideration of segregates had some psychological effect. If it were true that the effect of segregates could be reduced by altering the heat treatment and by using higher tempering, at the same time remembering that certain levels of strength must be obtained, then this information was of distinct value.

Transformations Due to Tempering.

The two last papers considered at the meeting were discussed jointly after presentation; they were entitled "Structural Transformations in the Tempering of High-Carbon Martensitic Steels," by Dr. K. H. Jack; and "Magnetic Analysis of Iron-Carbon Alloys: The Tempering of Martensite and Retained Austenite," by Mr. J. Crangle and Professor Sucksmith, F.R.S. Both papers contained descriptions of work carried out on behalf of the British Iron and Steel Research Association. The paper by Dr. Jack was presented by Dr. W. H. Taylor on behalf of the author, who is in the United States. In his paper, Dr. Jack stated that his results showed that the transformation of martensite to cementite occurred in two stages. The initial body-centred tetragonal martensite structure transformed very easily to a hexagonal closely-packed iron carbide. It was proposed that this iron carbide should be named ϵ-iron carbide, on account of its structural similarity to ϵ-iron nitride. Each of the two stages of transition of martensite to cementite could take place by relatively small movements of iron atoms, and the structural changes could be correlated with the well-known changes in hardness and specific volume which took place in steel during tempering.

When presenting the paper by Professor Sucksmith and himself, Mr. Crangle stated that, during recent years, it had become apparent that the observation of structure-insensitive magnetic properties, particularly magnetic saturation intensity and its variation with temperature, had led to a useful method of investigating problems concerning metals. The method could often be applied where other techniques, such as X-ray diffraction, were less sensitive, and, from its use, quantitative information could be obtained regarding phases in alloys. In the present work, the method had been used to examine the phases involved when quenched pure iron-carbon alloys were reheated. It had been found that, during the first stage of the martensite breakdown, a ferromagnetic phase different from cementite was precipitated. Retained austenite was found to change into the same state as did martensite. After heating to 300 deg. C., cementite and another carbide with composition and magnetic properties similar to those of iron percarbide ($Fe_{20}C_9$), were found to be present.

Mr. E. H. Bucknall, who opened the discussion, stated that Mr. Crangle and Professor Sucksmith's work seemed to be an outstanding example of how much could be ascertained by indirect physical methods, provided the experimental work, and particularly the interpretation of the results, were in expert hands. The fact should be emphasised, however, that both papers dealt with iron-carbon alloys rather than with steels, and very little was said about the materials used. Both papers referred to the presence of austenite in the quenched alloys, but only Mr. Crangle and Professor Sucksmith had indicated how much, and then only in one of the alloys. It would be of interest to hear what were the estimated austenite contents of their other alloys, and particularly of that containing 1·7 per cent. carbon. This subject bristled with difficulties of nomenclature. Thus, "ϵ-carbide" did not seem to mean the same thing in the two papers, and Dr. Jack had found it necessary to vary this expression with ϵ–Fe_2C and ϵ–Fe_3C.

Mr. D. McLean said that there was one aspect of the problem of the decomposition of martensite which was still unsolved, namely, the explanation of the changes which occurred in terms of the inter-atomic forces. It should be remembered that the free-energy curve for the carbide must be considered. At an early stage of transformation, of tempering of the martensite, the tetragonal form or iron was in equilibrium with the early carbide precipitate, but at a later stage the situation was different, with the cementite globules in equilibrium with the body-centred cubic phase at the lower carbon content. Hence, at some stage during tempering there would be a discontinuous switch-over from the tetragonal to the body-centred cubic form and, at the same time, a discontinuous drop in the carbon content of the iron phase. Mr. D. V. Wilson, who spoke next, said that at the end of his paper Dr. Jack had drawn attention to certain resemblances between the X-ray diffraction effects which accompanied the third stage of tempering and those which were to be observed in a cold-worked steel. Almost ten years ago, Professor Andrew had drawn some very striking comparisons between the properties of cold-worked steels and those of heat-treated steels, and he had suggested that there might be similarities in the changes involved in the two processes. In fact, of course, some of the resemblances were coincidental, and probably this was true of some of the X-ray diffraction effects in the two cases. Clearly, further experimental evidence was required, but he suggested that it might be these similarities which underlay certain resemblances in the properties—for example, certain aspects of the magnetic behaviour—of tempered, quench-hardened steels and cold-worked steels. The next speaker, Dr. K. Hoselitz, said that among the significant points of this work were the proof of the existence of a carbide phase different from cementite, possibly iron percarbide, and the determination of its limits of concentration; the proof of the identity of the products of decomposition of martensite and retained austenite; and the determination of the specific saturation intensity of martensite and cementite, and perhaps some other constituents.

The last speaker in the discussion, Dr. J. Nutting, referring to the mechanism for the breakdown of martensite, proposed by Mr. Crangle and Professor Sucksmith, stated that, in experiments conducted at the University of Cambridge, he and his colleagues had not been able to detect any intermediate carbide, $Fe_{20}C_9$. One other point was that he was not sure that it was correct to call the first-formed carbide Fe_2C. It was not just a matter of nomenclature; the passage from Fe_3C to Fe_2C should bring about a change in the microstructure. If it were assumed that the density of the Fe_2C was of the same order as that of the Fe_3C—and it was not likely to be very different—to go from one to the other should bring about a 50 per cent. increase in the volume of the iron carbide, and that should be visible in the microstructure. At Cambridge University, they had tried to extract some of the carbides from the steel and then determine their composition, both by X-ray diffraction and by submitting them to electron diffraction. By X-ray diffraction, it was found that the pattern which was thought to be cementite was indeed cementite, but by electron diffraction a picture of graphite was always obtained. That, it was thought, meant that when the carbides were extracted the composition at the surface of the carbide was changed and a region of graphite was the result. With X-ray diffraction, a much larger area was examined than was the case with electron diffraction, and that was why iron carbide was obtained. Probably the reason why some of these carbides were regarded as Fe_2C rather than Fe_3C was because there was an increase in the carbon content of the material extracted, and that gave the wrong chemical analysis, whereas what was happening was that, round the carbide, there was a film of graphite.

PROPOSED DEVELOPMENT OF LONDON TUBE RAILWAYS.

In 1949, a working party of the British Transport Commission submitted a report* to the Minister of Transport, which contained a number of proposals for the construction of new railways in London to carry both goods and passenger traffic. One of these railways, which was known as Route C, was to extend from the Tottenham area to the West End. It was to connect King's Cross, Euston and Victoria, then to pass under the river and follow the line of the main London road to Croydon. This route was to be given the highest priority, owing to the new facilities it would provide in a densely-populated area and the valuable new connections it would permit. Planning has therefore since been concentrated upon it and some account of what has been done in this direction was given in a paper read by Mr. F. G. Maxwell before the Railway Students' Association on Wednesday, December 5.

From Seven Sisters (Tottenham), the line, said Mr. Maxwell, would run in tube to the existing station of the Piccadilly line at Manor House. The Piccadilly line would be diverted round the station in a new pair of tunnels and then run on its present alignment to Turnpike Lane and the north. The reason for this change was that the station was at present mainly used by passengers from the trolley 'buses coming down Seven Sisters-road and these would have already been catered for by the new route. At Finsbury Park, the next station, the tunnels of the Northern city line would be used to provide cross-platform interchange between the new route and the Piccadilly line, thus providing relief to the latter. It was presumed that, by the time the new route was completed, the Northern city line trains would have been diverted into the new tunnels at Drayton Park and would be running into the surface station at Finsbury Park. Between Finsbury Park and King's Cross, the new line would run a little to the east of the Piccadilly line with a station at Highbury, where cross-platform interchange would be made with the Northern line and perhaps also with the London Midland Region lines from Broad-street to Richmond and Watford.

At King's Cross, the new line would run below the Circle line and above the Piccadilly line, with the Northern line below the latter. As cross-platform interchange was impossible, staircases and escalators would be provided. At the present time, King's Cross station was the busiest on the London Transport system (handling 50 million passengers per annum), and to deal with the increased traffic which would flow from the new route it would be necessary to enlarge the present booking hall, install escalators leading to the new platforms and improve the access to the Eastern Region main-line station.

At Euston, the next station on the new line, cross-platform interchange would be provided with the city loop of the Northern line. An additional station would be built at Warren-street with interchange with the existing station at that point, while at Oxford Circus extensive rebuilding would be necessary. This would include a new booking hall under the Circus itself, with escalators serving all lines as well as cross-platform interchange with the Bakerloo and Central lines. The main feature of the arrangement, which should have the effect of easing the heavy interchange which now occurred under less favourable conditions at Leicester Square and Charing Cross, was that one-way traffic movements were provided for throughout, both between the surface and the platforms and in the interchange passages. Road congestion should also be reduced as entrances to the station would be provided at all four corners of the Circus. The other main West End station was Green Park, where substantial interchange traffic was expected with the Piccadilly line. The two lines, however, must cross at right angles, so the design of the new station allowed for an enlargement of the present ticket hall, with two separate banks of escalators and an interchange subway.

The present London Transport station at Victoria served 34 million passengers per annum, and the Working Party's plan provided for two tubes with interchange between both the District and Circle line stations and the Southern Region station. The new tube station would be situated under the present 'bus forecourt with escalators running up to a new booking hall and access to the concourse of the main-line stations. Separate interchanges were planned from an intermediate level to the District and Circle lines station, the booking hall of which would remain as at present, and between the platforms of the new tube stations.

As the northern end of the new line was considered to warrant a higher priority than the southern end it was likely that the section as far as Victoria would be constructed and opened first. To provide the balanced traffic which was desirable, it might have a temporary western outlet from Victoria, possibly over one of the four western branches of the District line, such as that to Wimbledon. This possibility had been borne in mind in the design of the new station. Eventually, however, the line would continue southwards from Victoria to Croydon, the first station being at Vauxhall, where there would be an interchange with the main line of the Southern Region. The next station would be at Stockwell, where there would be an interchange with the Northern line, followed by stations at Brixton, Streatham Hill and Norbury, all with connections to the Southern Region system. From Norbury the line would continue southwards to West Croydon, where it would bifurcate, one branch continuing eastwards to East Croydon and the other to stations near the Town Hall and South Croydon and running thence to a depot between Selsdon and Sanderstead.

Giving some further details, Mr. Maxwell said that the line would be mainly constructed in standard 12-ft. diameter tunnels, and at the northern end it would either be in tube until shortly before reaching the terminus at Wood-street, Walthamstow, or would break surface alongside the Tottenham and Hampstead line and run into a new station combining South Tottenham and Seven Sisters. It would then cross the Lea Valley on the surface on new tracks laid alongside the tracks of the Tottenham and Forest Gate line as far as Black Horse-road station. At the latter place it would again dip into tube as far as Wood-street. The

* See ENGINEERING, vol. 168, page 37 (1949).

PRESTRESSED-CONCRETE CANTILEVER FOOTBRIDGE AT SHREWSBURY.

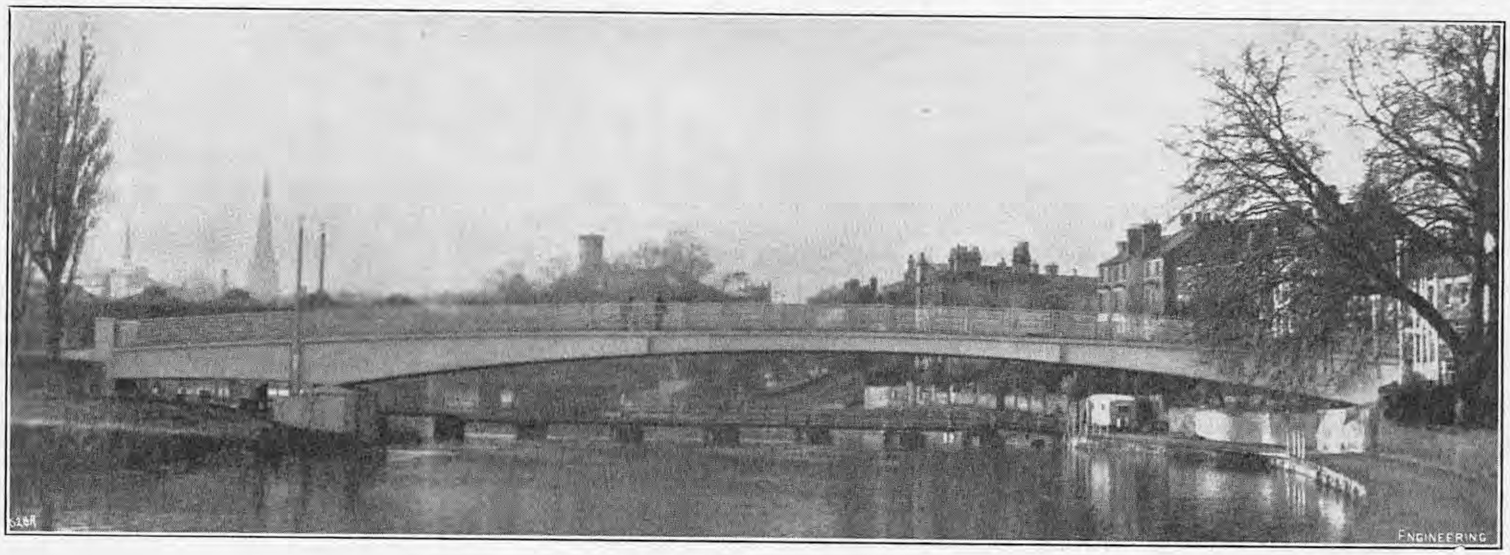


FIG. 1. CASTLE BRIDGE.

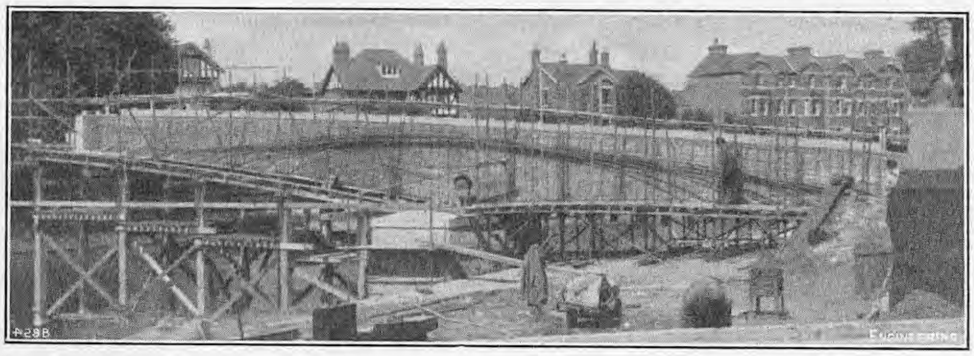


FIG. 2. CENTRE CANTILEVER ON SOUTH SIDE, UNDER CONSTRUCTION.

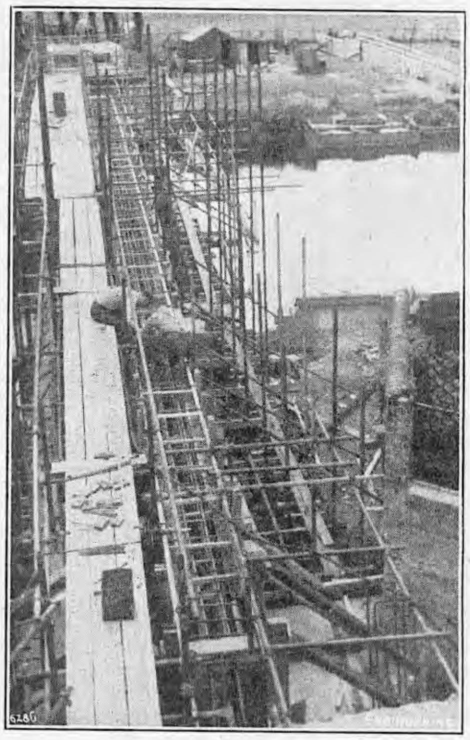


FIG. 3. NORTH-SIDE CENTRE CANTILEVER READY FOR RECEIVING CONCRETE.

tube solution had the advantage that the stations could be placed at the most favourable points from the traffic aspect, but the surface solution would probably be cheaper to build. In both cases, space for a depot for stabling and maintenance was very limited. As each alternative had its advantages and disadvantages, the final decision was likely to depend on detailed engineering estimates and the relative cost of the alignments and the two possible depot sites.

At Euston, the route would probably run "right hand" for a mile or so to encourage passengers from northern suburbs to the West End to travel by the first south-bound train and to use the cross-platform interchange at Euston if that train happened to be going to the City. This should even the loading between the City and West End trains, while extra capacity could be provided by extending the trains now reversing at Euston to Golders Green or Archway. A further advantage would be that passengers from Northern Line stations for Oxford Circus, Green Park or Victoria would be able to use the new convenient interchange at Euston and thus to relieve congestion at Tottenham Court-road, Leicester Square and Charing Cross. At Oxford Circus, there would be four new entrances, and passengers would descend to an intermediate level by escalators, where north and south bound passengers, as well as east and west bound passengers, would divide and reach the platforms by other escalators. Passengers leaving the platforms for the street would go up a stairway to an intermediate level, whence the existing three escalators, all of which would be ascending, would take them into the old station, and so to the street. Connection from the Central Line to the old station would be by two direct escalators. The layout would go as far as possible towards the ideal of separating all traffic flows both into and out of the station and would be of great value in handling heavy traffic.

If the new route terminated temporarily at Victoria, there would be an island platform with three sidings beyond it, so that a service of about 32 trains an hour could be reversed. If the route were given a temporary western outlet to reach a depot and provide balanced traffic, the two outside sidings would be extended to form running roads. In the final stage a second island platform would be built to provide interchange between the two new proposed routes. The main feature of these three plans was the way in which one stage led to the next, with the minimum of wasted construction of tunnels and junctions.

PRESTRESSED-CONCRETE CANTILEVER FOOTBRIDGE AT SHREWSBURY.

ON November 20, the Mayor of Shrewsbury, Councillor A. H. Jones, J.P., opened the new Castle Bridge across the River Severn at Shrewsbury. The new footbridge, which is illustrated in Fig. 1, is the first cantilever bridge of prestressed-concrete construction in the United Kingdom. The invitation for tenders issued by the Shrewsbury borough surveyor, Mr. F. R. Dinnis, specified "any form of construction, using any material, bearing in mind, *inter alia*, economy of construction, ease and economy of maintenance, eventual life, suitability to surroundings, and speed of erection." In competition with designs submitted in structural steelwork and normal reinforced concrete, the prestressed-concrete design entered by Messrs. Taylor Woodrow Construction, Limited, was selected, and it was built, in six months, in collaboration with Messrs. T. P. Bennett and Son, consulting architects, Messrs. L. G. Mouchel and Partners, consulting engineers, and the Prestressed Concrete Company, Limited. The use of the Freyssinet post-tensioned prestressed technique, it is claimed, has reduced the quantity of steel reinforcement by about 75 per cent., and has also resulted in a considerable saving in concrete.

The new bridge comprises two sets of three balanced cantilevers, cast *in situ* and the wires post-tensioned, supported on 3½-in. diameter steel roller bearings on the piers of the old suspension bridge. Four 60-ft. pre-cast girders are suspended over the river on 2½-in. diameter steel roller and rocker bearings at the ends of the cantilevers. Pre-cast concrete end blocks containing Freyssinet cones are used in all the main beams. Over the counterpoise blocks, the overall length of the bridge is 247 ft.; the width, over the main girders, is 11 ft. 6 in. The deck slab comprises pre-cast concrete slabs 3 in. thick, the gaps being filled with concrete cast *in situ*. The beams are 7 ft. deep at the piers and 2 ft. 9 in. deep at the centre of the suspended span. The soffit of the bridge is parabolic, with a rise of 7 ft. in 150 ft.; the deck has a longitudinal camber of 5·2 ft. in 247 ft.

The outer cantilevers are each 8 in. thick, and the centre cantilever is 16 in. thick. The three cantilevers are tied together and stiffened with cross-beams, spaced at 9-ft. centres at the top and 3 ft. at the bottom. At the top of the beam, a projecting flange, 4 in. wide, carries the pre-cast deck slabs. The suspended girders are of channel section with a 6½-in. thick web, and 12-in. wide flanges. They are stiffened by vertical ribs at 9 ft. centres. The suspended beams are tied together at the top by beams cast *in situ* after erection of the pre-cast units. Between the bottom flanges are freely-supported, at 3-ft. intervals, pre-cast beams carrying pipelines and cables for the water, gas, electricity, and General Post Office services. The bridge handrails are built up from rolled-steel sections, and panels of Weldmesh are fixed to the railings as additional protection.

Owing to the high floods which are liable to occur during the winter months—often some 15 ft. to 19 ft. above the ordinary low-water level, with a peak flood of 20 ft. 3½ in. recorded in February, 1795—it was essential to carry out the main part of the work during the six summer months. Even during the summer, the river has been known to rise 6 ft. or more above the towpath following heavy rain in the hills upstream. The first operation, before demolition of the old suspension bridge could be started, was to construct a temporary footbridge for pedestrians, adjacent to the main bridge; the river is 140 ft. wide between the towpath and the opposite bank at this point. Military pontoons, of braced plywood construction, 20 ft. long, 5 ft. 9 in. wide and 2 ft. 7 in. deep, spaced at 17-ft. centres, supported the temporary bridge. A 6-ft.

PRESTRESSED-CONCRETE CANTILEVER FOOTBRIDGE AT SHREWSBURY.

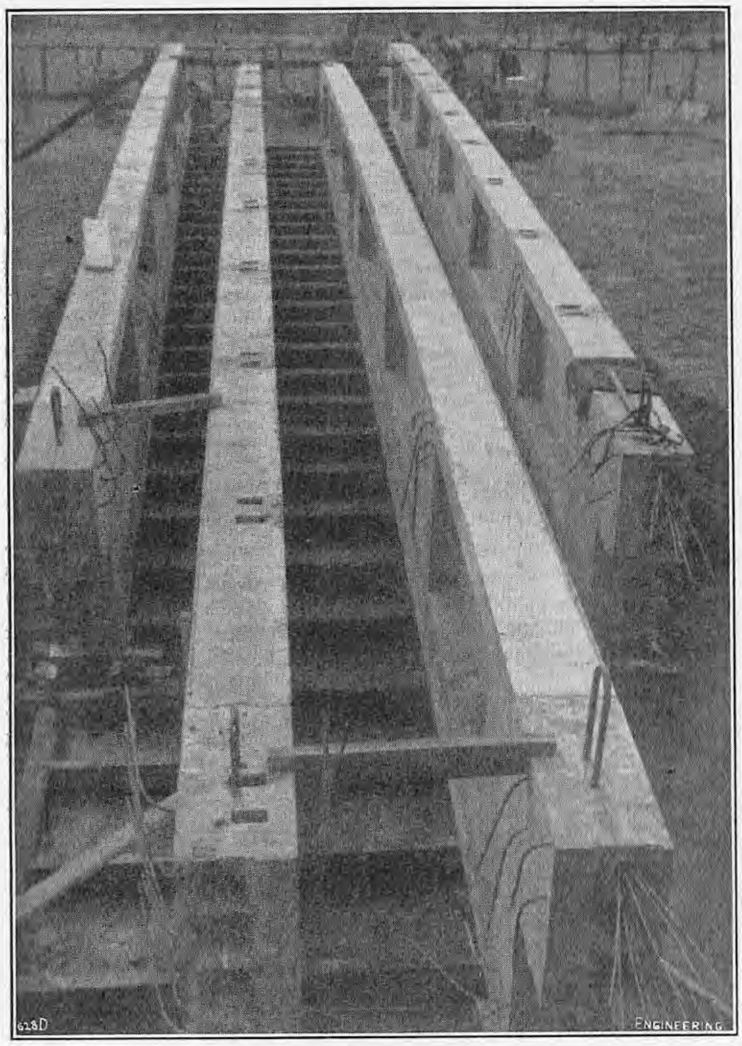


FIG. 4. FOUR PRE-CAST SUSPENDED BEAMS.

FIG. 5. POST-TENSIONING OPERATION ON PRE-CAST BEAMS.

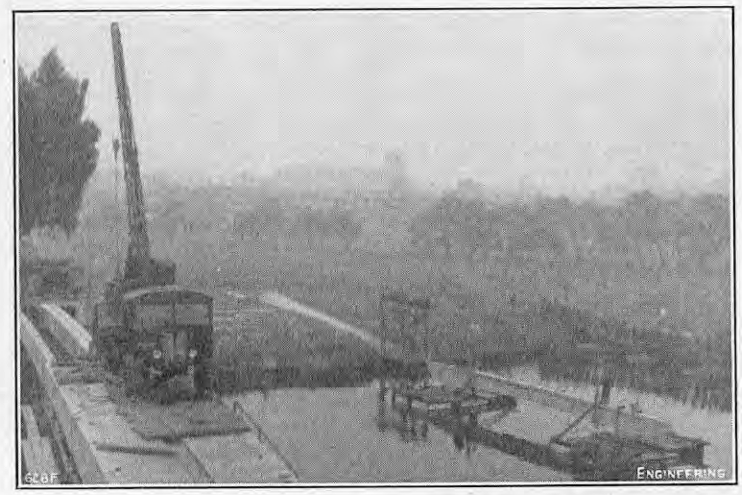


FIG. 6. CENTRE BEAM FLOATING DOWNSTREAM FOR HOISTING TO FINAL POSITION.

wide walkway was provided by timber boards, 2 in. thick, carried on two longitudinal beams 6 in. wide and 9 in. deep, resting on bearings on the pontoon. The longitudinal beams of adjacent spans were hinged at a point above the centre of the pontoon, to allow vertical movement of the decking and pontoons, and they were located on the bearers by vertical $1\frac{1}{4}$-in. diameter mild-steel pins on each side of the beam, which allowed a horizontal "pivoting" movement so that the bridge could deflect laterally, about 2 ft., under the pressure of river currents on the pontoons. The river current normally did not exceed about 2 or 3 m.p.h. To guard against the pontoons breaking away during floods, steel rings were fixed at each end of all the pontoons, through which was passed a $\frac{7}{8}$-in. diameter wire rope, fixed to anchorages at the river banks. At one end, between the wire rope and the anchorage, a pair of three-sheave rope blocks was connected; straining or easing of the free rope allowed a degree of control of the pontoon bridge to conform with the river level and water pressure.

The approach from the south side of the river is by an elevated walkway across a meadow, whereas the north approach is in a narrow built-up area. The south side was, therefore, used as a working base. The demolition of the suspension bridge was straightforward, and was completed in about three weeks. The original piers were lowered 6 ft. 3 in., and on them were cast reinforced-concrete caps incorporating the bearing plates for the $3\frac{1}{2}$-in. diameter steel rollers. To protect the south piers against the effects of isolation by erosion of the river bank, it has been enclosed by steel sheet piles tied together at the top with a reinforced-concrete ring beam; the gap between the piles and the pier was filled with mass concrete.

The counterpoise anchor blocks were located between the original suspension-bridge anchor blocks and abutments. Their construction was straightforward, but the excavations had to be kept open for four months while the main beams were constructed.

Steel scaffolding was erected to support the shore spans of the cantilever beams during construction, and a timber staging was built up on piles to carry the 45-ft. long cantilevers overhanging the river. Twenty-four 9-in. by 9-in. brushbox timber piles were driven approximately 9 ft. deep into the river bed, at 10 ft. by 5 ft. centres; the river bed is mainly 10 ft. to 16 ft. below the low-water level on the line of the bridge. On the piles, 9-in. by 9-in. brushbox timber posts were erected and secured by fishplates, and the staging was cross and horizontally braced in each plane above the water level. The tops of the posts were capped with 9-in. by 6-in. timbers, cantilevering over each side, to form supports for a walkway. Pairs of 6-in. by 3-in. rolled-steel channels spanned the 10-ft. interval between the timber caps on the ports, and supported the soffit shutters, or the new concrete beams. The staging was stabilised by $\frac{3}{8}$-in. diameter steel-wire guys fixed to the top and anchored at the river banks. Within the staging, a continuous working platform was provided about 5 ft. 6 in. below the beam soffit, to give access for stressing the Freyssinet cables which emerged from the soffit of the cantilevers. After the bridge was completed, the staging was removed and the piles were cut off at river-bed level by divers, either by a charge of gelignite, or by a compressed-air-driven circular saw. The staging can be seen in Fig. 2, which shows the centre cantilever beam on the south side of the river with some of the Freyssinet cables fixed in position.

Standard cables of 12 0·2-in. diameter high-tensile wires were used, enclosed in soft plastic sheathing. Ten cables were used for reinforcing the outer cantilevers, and 20 in the centre cantilevers. Accurate placing and supporting of the cables required considerable care. In Fig. 3, the reinforcement for the north-side centre cantilever is shown nearly complete and ready to receive concrete. All the concrete had to be placed from the tops of the beams where the Freyssinet cables were clustered above the pier support. The cables were stressed by a pair of Freysinnet jacks, one at each end of the cable. The free ends of the main cantilevers rose about $\frac{5}{16}$-in. under stressing; the gap so formed was wedged in order that a 16-ton crane could be traversed over the beams for hoisting the suspended span into position.

The four 60-ft. precast suspended beams were constructed on the south bank of the river, about 100 ft. upstream of the new bridge. Each suspended beam has six cables of the same type as in the cantilever beams. Fig. 4 shows the precast beams, and Fig. 5 the post-tensioning operation in progress, which caused the girders to lift $\frac{3}{8}$ in. at their centres. The pre-casting was carried out in a cutting excavated in the river bank at right angles to the river. An inclined concrete slab was laid in this cutting to carry the beams during construction and to form a slipway down which the completed beams were transferred, on 4-in. diameter steel rollers, to a timber-piled gantry at the end of the water. The movement of the beams down the slipway was controlled by two winches, one pulling and one retarding the beam, and by two sets of sway struts. An overhead travelling chain block on the gantry was used to lift the beams on to pontoons, one pontoon supporting each end of the beam as illustrated in Fig. 6. They were then floated downstream to the bridge. The suspended beams were lifted into position on the bridge by two 5-ton cranes mounted on lorries, each weighing 16 tons, and travelling under their own power to the ends of the cantilevers which, as already noted, were still supported by staging. Hoisting and lifting the suspended spans, which weigh $9\frac{1}{2}$ tons each, to their final position, took about $\frac{1}{2}$ hour; the whole operation for each beam took just over half a day. Careful handling was required, since the beams, which had a width-to-span ratio of 1 to 60, were very flexible laterally.

The cables were grouted with neat cement grout, the cement being sieved to remove any lumps, which tended to create stoppages. The grout was mixed in a colloidal grout machine. After the cable duct was full, the pressure was gradually reduced to prevent a back-throw of grout and a loss of grout from the duct. All the concrete used in the prestressed components was a high grade 1 : 1·3 : 2·6 mix. For normal reinforced-concrete components, a high-grade 1 : 2 : 4 mix was employed. A rapid-hardening Portland cement was used, with a water-cement ratio of about 0·45. All concrete was vibrated in position by immersion pencil-type vibrators. Three 6-in. test cubes were made of each placing of concrete, and were tested at 7, 14 and 28 days; a typical crushing-test result was 4,870, 5,760 and 6,450 lb. per square inch, respectively. Prestressing was permissible when the concrete attained a strength of 6,000 lb. per square inch, which was usually achieved at 14 days, but for other reasons stressing was not carried out until more than 28 days after the concrete had been placed.

NOTES FROM THE INDUSTRIAL CENTRES.

SCOTLAND.

FORTH ROAD BRIDGE.—Considerable progress has been made with the design for the Forth road bridge, it was reported at a meeting of Midlothian County Council in Edinburgh on December 12. It was stated that the two final borings had now been completed. The boring on the Mackintosh Rock on the Fife side of the river had been carried down 50 ft. into whinstone rock. The second, on the site of the other main tower, was carried down to 87 ft. below the bed of the river, where sandstone was met beneath a thick stratum of boulder clay.

THE LATE MR. E. J. EDGAR.—Mr. Edward James Edgar, M.I.E.E., controller of the South-West Scotland Division of the British Electricity Authority, died in an Edinburgh nursing home on November 10 after a brief illness; he was 62. Mr. Edgar came to Scotland in 1943 as manager for the Central and South Scotland areas of the Central Electricity Board. He was born at Prestbury, Cheshire, received his technical education at the Manchester College of Technology, and served his apprenticeship with two local firms. He filled, consecutively, posts with the Cleveland and Durham Electric Power Company, the Newcastle-on-Tyne Electric Supply Company, and the Belfast Corporation Electricity Department. Then followed a spell of five years with the Shanghai Power Company. His connection with the Central Electricity Board began in 1932, when he returned from the East to assume the post of operation engineer for the South-West England and South Wales area. He then became manager for North-East England, and subsequently manager for Central and South Scotland.

IRON AND STEEL PRODUCTION.—The Scottish output of steel ingots and castings expanded during November to the annual equivalent of 2,204,100 tons as compared with 2,147,800 tons in October. The corresponding rate in November last year was 2,590,700 tons. Production during the first nine months this year was at an annual rate of 2,098,400 tons, against 2,392,700 tons in the corresponding period of 1950. The final total for last year was 2,426,200 tons. Pig iron production has been higher than last year, the output in the first nine months being equivalent to 769,100 tons per annum, compared with 700,700 tons last year.

CLYDE SHIPBUILDING INDUSTRY.—New ships completed at Clyde yards during the first ten months of this year totalled 58, making together 339,000 tons gross. They comprised 16 oil tankers totalling 180,000 tons, 12 cargo ships aggregating nearly 77,000 tons, seven passenger vessels comprising 68,700 tons, and 23 miscellaneous craft making together 13,300 tons. Seven ships—two tankers, three cargo ships and two whalers—were handed over by Clyde firms to their owners in November, and a further 33,000 tons gross will be added to the total when three tankers now at the trials stage are handed over, the resultant totals being 68 ships and just under 410,000 tons.

NEWPORT FERRY PIER, DUNDEE.—Reconstruction of the Newport ferry pier, on lines similar to that now being carried out on the other side of the Tay ferry at Dundee, is under consideration by Dundee Harbour Trust, it was stated at a meeting of Fife County Road Board on December 7. Mr. T. McCallum, deputy county road surveyor, said that the Trust's reconstruction scheme in Dundee would ensure that vehicles waiting to cross by the ferry did not have to stand on the highway, but could be accommodated near the harbour.

CLEVELAND AND THE NORTHERN COUNTIES.

IRON AND STEEL INDUSTRY.—Conditions in the iron and allied trades continue to occasion grave anxiety and indications of early change for the better in the future are few and small. Producers are unable to cope with delivery obligations and the fear is expressed that outputs will have to be reduced, mainly because of inadequate deliveries of iron and steel scrap, raw materials and semi-finished commodities. Some slight improvement in coal output, however, is a development that encourages the hope of an expansion in the manufacture of North-East Coast products urgently needed in large quantities for important home purposes and for shipment overseas. If more coke becomes available an expansion of pig-iron production could soon be achieved but, as yet, the position has not improved to an extent that justifies preparations for the re-kindling of blast-furnaces that have been idle for some time. A rise in pig-iron supplies would be followed speedily by increased activity at consuming plants.

SPEEDING UP MOVEMENT OF IRON ORE.—Complaints are heard, from time to time, of serious transport difficulties in the North-East Coast iron and steel-producing areas due to an insufficient supply of railway wagons, and the announcement of a movement to deal energetically with the matter is most welcome. British Railways have designed an iron-ore wagon with pneumatic discharge gear, and 30 of these are in course of construction at Shildon, Co. Durham. Trains of the wagons are to carry 4,500 tons of iron ore a day from Tyne Dock to the Consett steelworks. The first train of ten wagons is expected to be ready in the spring. A scheme developed by the Tyne Improvement Commission and the Consett Iron Co., Ltd., aims at handling 1,250,000 tons of iron ore a year from ship to works.

FLOOD PROBLEM AT DARLINGTON.—The Streets Committee of the Darlington Town Council have met representatives of the Wear and Tees River Board to discuss the problem of flooding at Haughton, Darlington. This is caused by silting in the River Sterne, and the outcome of the meeting is that it is hoped that the Corporation of Darlington and the River Board will co-operate in carrying out re-grading and other works on the river to end the trouble.

LANCASHIRE AND SOUTH YORKSHIRE.

POWER CUTS.—Sheffield and Rotherham industrialists have been fortunate in that it has not been necessary to impose power cuts except on odd occasions so far this winter, thanks largely to the operation of staggered hours; and it was not until December 14 that it became necessary to ask 130 firms in the Sheffield district to make a 15 per cent. reduction in gas consumption for 48 hours. Sheffield recently achieved a new record output of gas, and if the new plant at Neepsend, now nearly ready, had been in use, it would have been possible to meet the peak demand.

REVISED GAS CHARGES.—The East Midlands Gas Board has announced standard tariffs for gas which will mean an increase in top gas prices of nearly 2*d.* a therm for Sheffield and Rotherham users, but reductions at Chesterfield and many other places. At Doncaster, the price will go up by 0·6*d.* a therm. In place of nearly 400 different prices in the area there are now five prices for domestic users, according to where they live, and six for non-domestic users. A sliding scale will reduce the charge for consumptions of more than 30 therms per quarter. The domestic meter rent is abolished.

LOW STEEL STOCKS.—Stocks of steel at Sheffield are very low and are said to have touched rock bottom. The wintry weather has adversely affected railway transport and delayed the receipt of scrap and other melting materials. Steel manufacturers have been apprehensive of a repetition of the experience in the winter of 1947 when the weather was the cause of a production crisis. The weekly production of steel ingots and castings in the Sheffield district in November, namely, 44,200 tons, increased by 1,700 tons a week over the October output and was the highest since April.

THE MIDLANDS.

UNDERGROUND GASIFICATION OF COAL.—Mr. C. A. Masterman, technical director of underground gasification, Ministry of Fuel and Power, announced in Birmingham on December 12 that it was hoped to ignite a coal seam at a depth of 100 ft. at Rock, Bewdley, Worcestershire, early next year. The Rock area has a number of seams which are unworkable by any normal mining method, and a site of seven acres is being used for the experiments. It is hoped that a second seam, at a depth of 250 ft., will be ignited later in 1952. A pilot plant for the generation of electricity with turbines driven by the gas is planned for the autumn of 1953, and it is hoped to produce current at a cost not greater than the electricity authorities pay at present for their fuel. The Rock experiments are the second to be undertaken in this country, the first being at Newman Spinney, near Chesterfield, in 1949.

AN ALL-ELECTRIC COLLIERY.—It is planned to start boring for coal at Bevercoats, between Retford and Ollerton, Nottinghamshire, to tap the Deep Hard seam which has yielded high outputs at the newer collieries of the Dukeries coalfield. It is expected that the colliery, which will be all-electric, will eventually yield 5,000 tons of coal a day and employ 18,000 men. Two shafts are to be sunk, each about 24 ft. in diameter, to a depth of about 1,000 yards to reach the Top Hard seam, which is about 4 ft. thick.

THE SHEET AND STRIP METAL USERS' TECHNICAL ASSOCIATION.—A Midland branch of the Sheet and Strip Metal Users' Technical Association has been formed in Birmingham. The names of the following Midland officers have been announced: chairman, Mr. M. E. Guermont (Fisher & Ludlow, Ltd., Birmingham); honorary secretary, Mr. E. N. Salmon (Austin Motor Co., Ltd., Birmingham). The Midland committee consists of Mr. W. Beresford (Fisher & Ludlow, Ltd.); Mr. E. Coupland (Rubery, Owen & Co., Ltd., Darlaston); Mr. L. Gibbs (Metal Sections, Ltd., Oldbury); and Mr. G. C. Hoare (J. F. Ratcliff (Metals), Ltd., Birmingham).

STAFFORDSHIRE COUNTY TECHNICAL COLLEGE, WEDNESBURY.—Mr. T. G. Bamford, M.Sc., A.R.I.C., M.I.Prod.E., who has been principal of the Staffordshire County Technical College at Wednesbury since 1928, is retiring shortly. Wednesbury College is one of the largest in the Black Country, and during Mr. Bamford's tenure of office, the number of students has risen from 250 to nearly 1,400. Mr. Bamford is to be succeeded by Mr. H. A. McColl, B.Sc. (Hons. Met.), F.I.M., the present head of the metallurgy department.

RUBBER RESEARCH CENTRE.—The Research Association of British Rubber Manufacturers have acquired premises at Shawbury, Shropshire, for use as research laboratories. The buildings, which were erected as casual wards by Shropshire County Council, are about six miles N.E. of Shrewsbury. Some of the staff of the present headquarters at Croydon will be transferred to the new centre, and others will be recruited locally. It is expected that the Shawbury premises, which will become the Association's headquarters, will be opened in about two years' time.

HEREFORD WATERWORKS.—Following the recent failure of water supplies to the city of Hereford, the corporation have decided to spend 22,000*l.* on improvements to the waterworks. The waterworks committee have reported that, when the flooding of the river Wye caused a breakdown of the water supply, the position was aggravated by the fact that an electric motor, which had been sent away for re-winding, had not been returned, and part of the plant was out of commission.

SOUTH-WEST ENGLAND AND SOUTH WALES.

BRIDGES OVER RIVER TAMAR.—The Minister of Transport, the Hon. J. S. Maclay, M.P., received, on December 11, a deputation from the Cornwall County Council, the Plymouth City Council and the Saltash Borough Council to discuss the questions of the construction of a high-level bridge over the River Tamar, at Saltash, and the provision of a third floating bridge for the Torpoint Ferry. It was agreed that the construction of the high-level bridge had to be regarded as a long-term project, but the Minister undertook to examine the deputation's representations in favour of carrying out a limited amount of preliminary survey work in the near future to fix the site of the bridge. As regards the provision of the third floating bridge, the Minister expressed sympathy with the present conditions of congestion, but pointed out the difficulties arising from the restrictions on capital investment.

REMOVAL OF ROLLING MILL TO SCUNTHORPE.—Details of the move of the company's 750,000*l.* steel wire-rod rolling mill from Cardiff to Scunthorpe, Lincolnshire, have been given during the past week by Mr. N. R. R. Brooke, managing director of Guest Keen and Nettlefolds (South Wales), Ltd. The move is being made to avoid the necessity to send steel from Scunthorpe to South Wales to manufacture wire rod. In accordance with the development plans for the industry, prepared by the Iron and Steel Corporation of Great Britain, the steel wire-rod mill which has been in operation at Cardiff since 1935 is to close down at Christmas. The mill is being completely modernised and reinstalled alongside the iron and steel works of John Lysaght (Scunthorpe), Ltd., which are also being modernised. A new and completely modern wire-rod mill was installed at the Tremorfa works, Cardiff, by the company, a little over a year ago to produce the wire rods required in the area.

RHOOSE AERODROME.—Cardiff Corporation has been told by the Ministry of Civil Aviation that the restoration of Rhoose Aerodrome to render it suitable as a terminal for Dakota aircraft may be delayed by restrictions on capital investment. Detailed surveys, the Ministry states, have shown that there would be no physical difficulties regarding the use of the aerodrome for services operated by Dakotas.

COAL FOR GAS-MAKING.—Llanelly gasworks have been selected for an important project in 1952 aimed at widening the scope of the coals suitable for gas-making. This was announced by Mr. Albert Pickard, manager and secretary of the Llanelly undertaking. He said that the new process would mean completely gasifying the coal, and that low-volatile coal, different from that normally used, would be employed.

NOTICES OF MEETINGS.

IT is requested that particulars for insertion in this column shall reach the Editor not later than Tuesday morning in the week preceding the date of the meeting.

JUNIOR INSTITUTION OF ENGINEERS.—Friday, December 28, 6.30 p.m., 39, Victoria-street, S.W.1. "Hydro-Electric Power Developments," by Mr. J. Foster Petree. *Midland Section:* Wednesday, January 2, 7 p.m., James Watt Memorial Institute, Birmingham. "The Manufacture of Coins," by Mr. G. H. Thompson. *Institution:* Friday, January 4, 6.30 p.m., 39, Victoria-street, S.W.1. Film on "Rocket Flight," introduced by Mr. S. G. Clark. *North-Western Section:* Monday, January 7, 7.30 p.m., 16, St. Mary's Parsonage, Manchester. Chairman's Address, by Mr. A. Eaton.

INCORPORATED PLANT ENGINEERS.—*South Wales Branch:* Tuesday, January 1, 7.15 p.m., South Wales Institute of Engineers, Park-place, Cardiff. Film on "Hard Surfacing with Stellite." *Southampton Branch:* Wednesday, January 2, 7.30 p.m., Polygon Hotel, Southampton. Discussion on "The Factories Act." *Peterborough Branch:* Thursday, January 3, 7.30 p.m., Offices of the Eastern Gas Board, Church-street, Peterborough. "Power Distribution," by Mr. G. J. Richardson. *Edinburgh Branch:* Tuesday, January 8, 7 p.m., 25, Charlotte-square, Edinburgh. "Organisation of Scientific Research in Great Britain," by Dr. H. Buckley. *East Lancashire Branch:* Tuesday, January 8, 7.15 p.m., Engineers' Club, Manchester. "Secondary Air and Its Application," by Mr. H. Hetherington. *East Midlands Branch:* Wednesday, January 9, 7 p.m., Welbeck Hotel, Nottingham. "Building a Passenger Liner," by Mr. J. Melville. *Kent Branch:* Thursday, January 10, 7 p.m., Queen's Head Hotel, Maidstone. "Automatic Combustion Control as Applicable to Industrial-Type Boilers," by Mr. S. J. Clifton.

INSTITUTION OF PRODUCTION ENGINEERS.—*Reading Section:* Tuesday, January 1, 7.15 p.m., Great Western Hotel, Reading. "Industrial Design and the Engineer," by Mr. K. L. Brookfield. *Wolverhampton Section:* Wednesday, January 2, 6.30 p.m., Star and Garter Hotel, Wolverhampton. Film on "Polished Plate Glass and 'Armourplate' Glass." *Nottingham Section:* Wednesday, January 2, 7 p.m., Victoria Station Hotel, Nottingham. "The Importance of Costing to the Production Engineer," by Mr. L. W. Robson. *London Section:* Thursday, January 3, 7 p.m., Old Ship Hotel, Brighton. "Improvements and Their Hindrances," by Mr. C. R. Whitaker. *Halifax Section:* Monday, January 7, 7.15 p.m., George Hotel, Huddersfield. "Steam Turbine Manufacture," by Mr. A. C. Annis.

INSTITUTION OF HEATING AND VENTILATING ENGINEERS.—*East Midlands Branch:* Wednesday, January 2, 6.30 p.m., Victoria Station Hotel, Nottingham. "Special Applications of Air Conditioning," by Dr. B. Edgington. *North-East Coast Branch:* Tuesday, January 8, 6.30 p.m., Neville Hall, Westgate-road, Newcastle-upon-Tyne. "School Heating," by Dr. J. C. Weston. *Institution:* Wednesday, January 9, 6 p.m., Institution of Mechanical Engineers, Storey's-gate, St. James's Park, S.W.1. "Fibrous Filters for Fine-Particle Filtration," by Dr. D. J. Thomas.

INSTITUTION OF MECHANICAL ENGINEERS.—*London Graduates' Section:* Wednesday, January 2, 6.30 p.m., Storey's-gate, St. James's Park, S.W.1. "The Development of the Mechanical Principles of Punched-Card Accounting Machines," by Mr. P. W. Murphy. *Institution:* Friday, January 4, 5.30 p.m., Storey's-gate, St. James's Park, S.W.1. "Considerations on Bogie Design, with Particular Reference to Electric Railways," by Mr. W. S. Graff-Baker. *North-Eastern Branch:* Monday, January 7, 6 p.m., Neville Hall, Westgate-road, Newcastle-upon-Tyne. Annual Meeting. "The Measurement and Interpretation of Machinery Noise, with Special Reference to Oil Engines," by Mr. C. H. Bradbury. *South Wales Branch:* Tuesday, January 8, 6 p.m., South Wales Institute of Engineers, Park-place, Cardiff. Thomas Hawksley Lecture on "Some Fuel and Power Projects," by Dr. H. Roxbee Cox. *Scottish Branch:* Thursday, January 10, 7.30 p.m., Royal Technical College, Glasgow. "Steel Castings and the Engineers," by Mr. J. F. B. Jackson. AUTOMOBILE DIVISION.—*Birmingham Centre:* Tuesday, January 1, 7.15 p.m., Craven Arms Hotel, Coventry. "Shock Absorbers," by Mr. J. W. Kinchin and Mr. C. R. Stock. *Western Centre:* Thursday, January 3, 6.45 p.m., Royal Hotel, Bristol. Informal Discussion.

INSTITUTION OF ENGINEERING INSPECTION.—*Birmingham Branch:* Wednesday, January 2, 7.30 p.m., Chamber of Commerce, 95, New-street, Birmingham. "Petroleum Products," by Mr. K. H. Holman. *Institution:* Thursday, January 3, 6 p.m., Royal Society of Arts, John Adam-street, W.C.2. "Quantity Production of Geared Instruments for Time and Linear Measurements," by Mr. T. G. Mercer.

INSTITUTE OF METALS.—Thursday, January 3, 2.30 p.m., The University, Birmingham. Discussion on "Tool and Die Materials for the Hot-Working of Non-Ferrous Metals and Alloys." *London Local Section:* Thursday, January 3, 7 p.m., 4, Grosvenor-gardens, Westminster, S.W.1. "Research on the Working of Metals," by Mr. W. C. F. Hessenberg.

LEEDS METALLURGICAL SOCIETY.—Thursday, January 3, 7 p.m., The University, Leeds. "The Platinum Metals: Their Properties and Uses," by Dr. J. C. Chaston.

INSTITUTION OF WORKS MANAGERS.—*Tees-Side Branch:* Thursday, January 3, 7.30 p.m., Vane Arms Hotel, Stockton. "The Profession of Management," by Mr. A. M. Hudson Davies. *Merseyside Branch:* Tuesday, January 8, 6.30 p.m., Adelphi Hotel, Liverpool. "Management Practice in the United States," by Mr. E. Packer. *Birmingham Branch:* Tuesday, January 8, 7 p.m., Grand Hotel, Birmingham. "Production Economy," by Mr. T. A. Yapp.

ILLUMINATING ENGINEERING SOCIETY.—*Birmingham Centre:* Friday, January 4, 6 p.m., Imperial Hotel, Birmingham. Joint Meeting with INSTITUTE OF ROAD TRANSPORT ENGINEERS. "Modern Transport Lighting," by Mr. W. E. J. Drake. *Bath and Bristol Centre:* Friday, January 4, 7 p.m., Offices of the South Western Electricity Board, Old Bridge, Bath. "Neon Lighting," by Mr. C. Higgins.

INSTITUTION OF ELECTRICAL ENGINEERS.—*South Midland Centre:* Monday, January 7, 6 p.m., James Watt Memorial Institute, Birmingham. "Protection of Electrical Power Systems: A Critical Review of Present-Day Practice and Recent Progress," by Mr. H. Leyburn and Mr. C. H. W. Lackey. *Mersey and North Wales Centre:* Monday, January 7, 6.30 p.m., Royal Institution, Colquitt-street, Liverpool. "Modern Developments in Electric Welding," by Dr. H. G. Taylor. *Measurements and Radio Sections:* Tuesday, January 8, 5.30 p.m., Savoy-place, Victoria-embankment, W.C.2. (i) "Two Electronic Resistance or Conductance Meters," by Dr. L. B. Turner. (ii) "A Bridge for the Measurement of the Dielectric Constants of Gases," by Mr. W. F. Lovering and Mr. L. Wiltshire. *North-Western Centre:* Tuesday, January 8, 6.15 p.m., Engineers' Club, Manchester. "Electricity in Newspaper Printing," by Mr. A. T. Robertson. *North Midland Centre:* Tuesday, January 8, 6.30 p.m., Hotel Metropole, Leeds. (i) "Crystal Diodes," by Mr. R. W. Douglas and Dr. E. G. James. (ii) "Crystal Triodes," by Mr. T. R. Scott. *Southern Centre:* Wednesday, January 9, 6.30 p.m., Polygon Hotel, Southampton. "Domestic Electrical Installations: Some Safety Aspects," by Mr. H. W. Swann. *Scottish Centre:* Wednesday, January 9, 7 p.m., Heriot-Watt College, Edinburgh. "Transient Theory of Synchronous Generators Connected to Power Stations," by Mr. B. Adkins.

INSTITUTE OF BRITISH FOUNDRYMEN.—*Sheffield Branch:* Monday, January 7, 7.30 p.m., College of Technology, Pond-street, Sheffield. "Synthetic Resins as Foundry Sand Binders," by Mr. P. G. Pentz. *Burnley Section:* Tuesday, January 8, 7.30 p.m., Grammar School, Blackburn-road, Accrington. "Phosphor Bronze," by Mr. E. Jackson. *Lincolnshire Branch:* Thursday, January 10, 7.15 p.m., Technical College, Lincoln. "Production of Turbine Castings," by Mr. N. Charlton. *Middlesbrough Branch:* Friday, January 11, 7.30 p.m., at Messrs. Head, Wrightson and Co., Ltd., Teesdale Iron Works, Thornaby-on-Tees. "Process Planning in the Steel Foundry Industry," by Mr. S. L. Finch.

INSTITUTION OF CHEMICAL ENGINEERS.—Tuesday, January 8, 5.30 p.m., Geological Society, Burlington House, Piccadilly, W.1. "Froth Flotation Kinetics," by Mr. William Gibb.

INSTITUTE OF PETROLEUM.—Wednesday, January 9, 5.30 p.m., Manson House, 26, Portland-place, W.1. "Some Aspects of Field Operations in Kuwait," by Mr. E. Boaden and Mr. E. C. Masterson.

BRITISH INSTITUTION OF RADIO ENGINEERS.—*North-Eastern Section:* Wednesday, January 9, 6 p.m., Neville Hall, Westgate-road, Newcastle-upon-Tyne. "Test Gear Design," by Mr. A. W. Wray. *London Section:* Wednesday, January 9, 6.30 p.m., London School of Hygiene and Tropical Medicine, Keppel-street, W.C.1. "Crystal Triodes," by Dr. E. G. James and Mr. G. M. Wells.

INSTITUTION OF STRUCTURAL ENGINEERS.—*Northern Counties Branch:* Wednesday, January 9, 6.30 p.m., Cleveland Scientific and Technical Institution, Corporation-road, Middlesbrough. "Reconstruction of Houdon-on-Tyne Gas Works," by Mr. W. R. Garrett.

INSTITUTE OF ROAD TRANSPORT ENGINEERS.—*East Midlands Centre:* Wednesday, January 9, 7.30 p.m., Mechanics Institute, Nottingham. "Use of Aluminium for Road-Vehicle Bodies," by Mr. R. Esmonde.

INSTITUTE OF FUEL.—*North-Western Section:* Thursday, January 10, 2.30 p.m., Radiant House, Bold-street, Liverpool. "Progress in Domestic Heating Research," by Dr. A. C. Monkhouse.

INSTITUTION OF CIVIL ENGINEERS.—*Midlands Association:* Thursday, January 10, 6 p.m., James Watt Memorial Institute, Birmingham. "Sewage Purification," by Mr. David M. Watson.

PERSONAL.

SIR GEORGE BINNEY, D.S.O., B.A., F.R.G.S., and MR. K. F. PEARSON have been elected directors of the Vulcan Foundry, Limited, Newton-le-Willows, Lancashire.

COLONEL H. C. SMITH, C.B.E., D.L., J.P., M.I.C.E., M.Inst.Gas.E., is succeeding SIR EDGAR SYLVESTER, K.B.E., as chairman of the Gas Council, 1, Grosvenor-place, London, S.W.1, on January 1, 1952. Colonel Smith has been deputy chairman of the Gas Council since July 30, 1948.

PROFESSOR JOHN MACNAGHTEN WHITTAKER, F.R.S., Professor of Pure Mathematics at Liverpool University, has been appointed Vice-Chancellor of Sheffield University, in succession to Sir Irvine Masson, who is to retire next September.

AIR-COMMODORE W. WYNTER-MORGAN, C.B., C.B.E., M.C., who has an extensive knowledge of air armaments, has joined the staff of Sir W. G. Armstrong Whitworth Aircraft Co., Ltd.

MR. A. R. COOPER, M.I.E.E., M.Inst.F., controller of the Merseyside and North Wales generation division of the British Electricity Authority since 1948, and formerly chief operation engineer, Central Electricity Board, has been appointed controller of the North-Western generation division in succession to the late MR. C. T. S. ARNETT.

MR. HUGH BECK, B.Sc., A.M.I.Mech.E., M.I.Mar.E., London office manager of Crossley Brothers Ltd., Diesel-engine manufacturers, Openshaw, Manchester, has been appointed to a seat on the board of directors.

MR. J. HOLDEN FRASER, B.Sc., A.M.I.C.E., M.I.R.S.E., hitherto signal and telecommunications engineer, North Eastern Region, British Railways, York, has been appointed chief officer, engineering (signal and telecommunications) at Railway Executive headquarters, London.

The HON. J. R. REA has relinquished the position of Secretary of the British Electrical and Allied Manufacturers' Association, which he has held since 1938.

MR. P. D. IRONS, who originally joined Saunders-Roe, Ltd., in 1938 and has been secretary of the firm for seven years, has been elected to the board of directors. He is a director of the firm's two subsidiary companies, Saro Laminated Wood Products Ltd., and Saunders-Roe (Anglesey) Ltd.

MR. R. D. BROWN, A.M.I.C.E., formerly European representative of Richard Sutcliffe Ltd., Universal Works, Horbury, Wakefield, has been appointed sales manager to the firm.

MR. P. G. CLADISH is relinquishing his position as sales executive at the head office of the Brockhouse Organisation to assume that of sales manager of Brockhouse Engineering (Southport) Ltd., on January 1.

I.T.D., LTD., the selling organisation for Stacatrucs, Aerolift fork trucks and Electricar works trucks, state that MR. R. T. HARTMANN, M.A., is no longer connected with the company. MR. A. C. COOPER, who, until now, has been United Kingdom division manager, will be acting sales manager of the company, in charge of both home and overseas business.

DR. J. H. GARDNER has joined the petrochemical department of the National Research Corporation, 70, Memorial Drive, Cambridge, Massachusetts, U.S.A.

ROTARY HOES LTD., East Horndon, Essex, have formed a new distributing company in the United States. It is registered as the HOWARD ROTAVATOR CO., INC., and has headquarters at 3916, South Hanover-street, Baltimore, Maryland. It is responsible for the distribution of Howard Rotavators throughout the Eastern States.

At present, VICKERS-ARMSTRONGS LTD., and the METROPOLITAN-CAMMELL CARRIAGE AND WAGON CO., LTD., are represented in South Africa by VICKERS AND METROPOLITAN CARRIAGE (SOUTH AFRICA) LTD. The name of this, as from January 1, 1952, will be changed to VICKERS-ARMSTRONGS SOUTH AFRICA (PTY.) LTD., and, concurrently, a new company, METROPOLITAN-CAMMELL CARRIAGE AND WAGON COMPANY, AFRICA (PTY.) LTD., will be formed. Vickers-Armstrongs South Africa (Pty.) Ltd., will sell the products of Vickers-Armstrongs Ltd., in the Union of South Africa and the Rhodesias, and will also represent ROBERT BOBY, LTD., PALMERS HEBBURN CO., LTD., G. J. WORSSAM AND SON, LTD., and for certain of their products, IOCO LTD. The directors will be MR. D. W. STANLEY, chairman and managing director, MR B. L. BLAINE, MR. W. H. BUTLER, MR. J. A. KILLICK and MR. A. H. HIRD. The newly-formed company will take over the representation, in Africa, of the interests of the Metropolitan-Cammell Carriage and Wagon Co., Ltd., and will also represent, in the territory, GRESHAM AND CRAVEN, LTD., the LAYCOCK ENGINEERING CO., LTD., G. SPENCER MOULTON AND CO., LTD., the VACUUM BRAKE CO., LTD., and MALEY AND TAUNTON, LTD. The directors will be MR. D. W. STANLEY, chairman, SIR ARCHIBALD J. BOYD, MR. F. O. G. LONG, managing director, and W. A. J. DAY. The offices of both companies will continue to be in Maritime House, Loveday-street, Johannesburg.

COLD-REDUCTION SHEET AND TINPLATE MILL AT PITTSBURG, CALIFORNIA.

(*For Description, see Page* 769.)

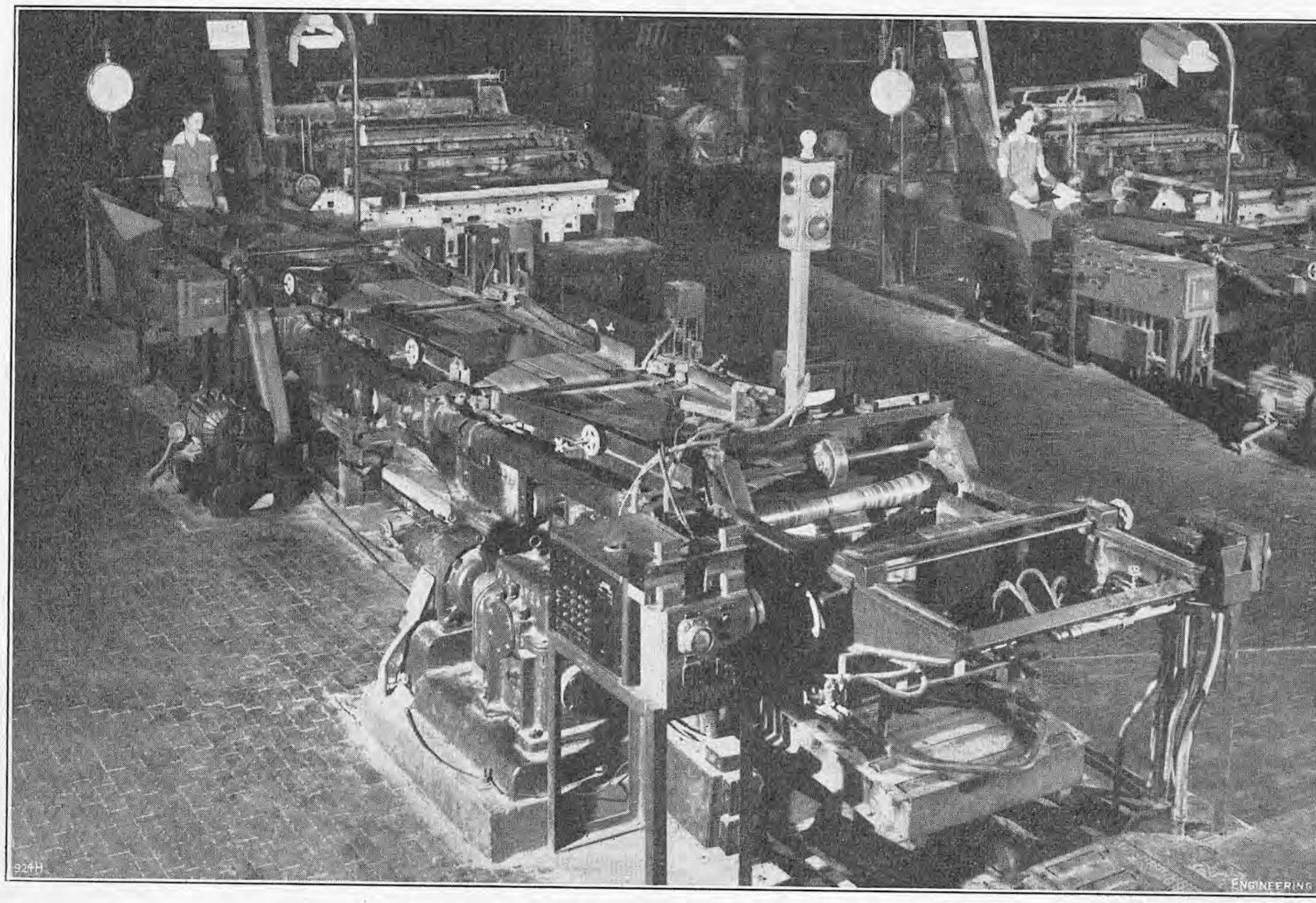


FIG. 7. DELIVERY END OF HOT-DIP TINNING LINE.

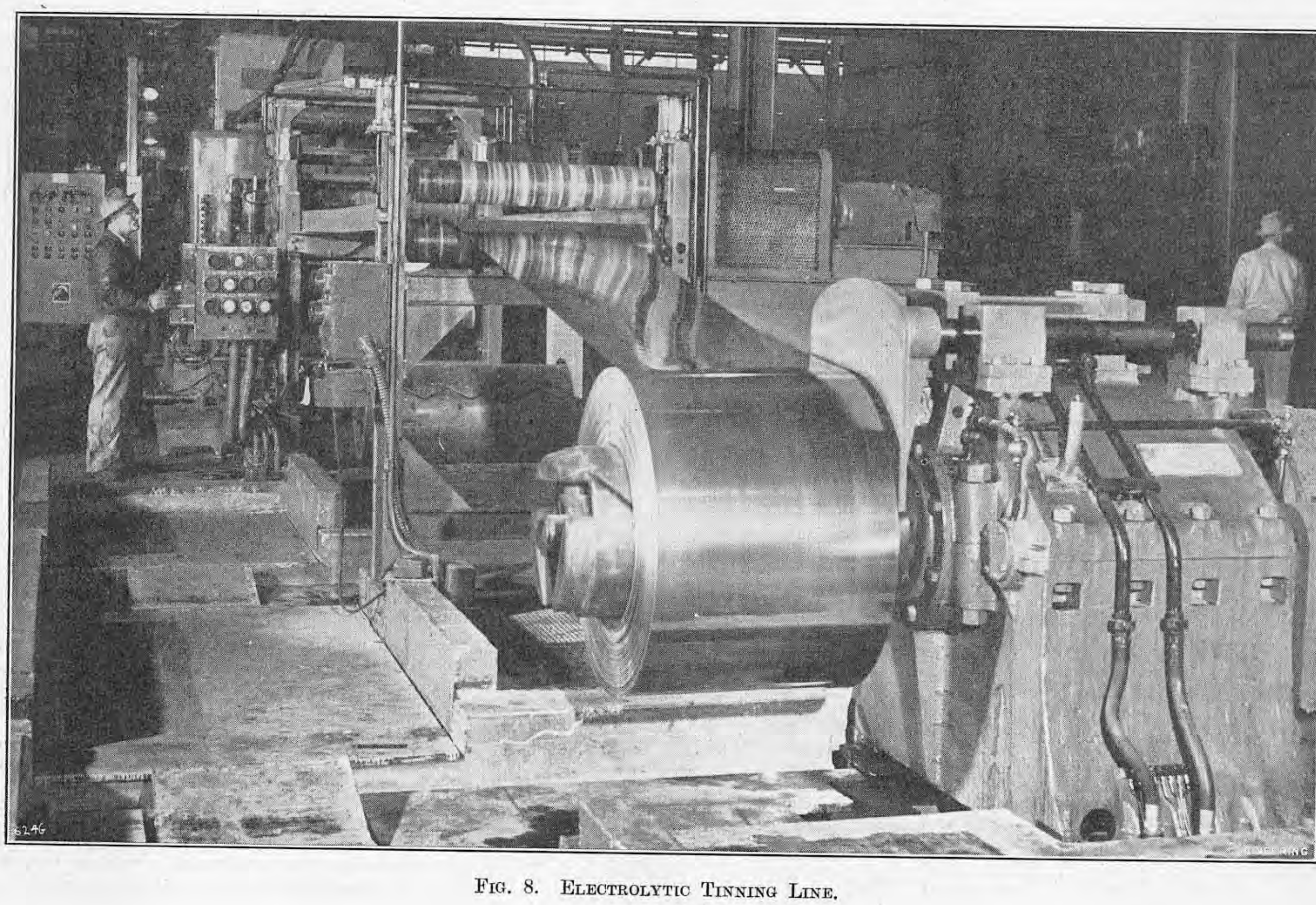


FIG. 8. ELECTROLYTIC TINNING LINE.

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INDEX TO VOL. 171.

The Index to Vol. 171 of ENGINEERING (January-June, 1951) is now ready and will be sent to any reader, without charge and postage paid, on application being made to the Publisher. In order to reduce the consumption of paper, copies of the Index are being distributed only in response to such applications.

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ENGINEERING

FRIDAY, DECEMBER 21, 1951.

Vol. 172. No. 4482.

BUILDING RESEARCH.

In May, 1944, the scope of the work of the Road Research Board was extended to include traffic flow and road accidents. A step of a similar kind was taken last year in connection with the Building Research Board ; from April, 1950, it has been required to take " responsibility for economic and sociological research on building." This enlargement of the fields of these two Boards may be presumed to indicate a growing realisation of the fact that matters involving social reactions, and bearing on the opinions and habits of the mass of the population, are likely to be investigated in a more unbiased way by a scientific body than by associations and committees which set out on their work with preconceived opinions. As the latest report* of the Building Research Board deals with its activities only up to the end of 1950, so that it covers only nine months' operations under the enlarged functions, it is not to be expected that it should contain much information about how the instruction to undertake " sociological " research is being interpreted.

The Board has been engaged in at least one branch of that kind of activity for many years, if, as seems reasonable, study of the reaction of the tenants of houses to different methods of construction and heating may be described as sociological research. The houses which the Board has built at Abbots Langley and Garston have been designed for the study of different types of construction and problems of heating, ventilation and sound transmission, but note has been taken throughout of tenants' reaction. This type of investigation is evidently being extended, and an extra-mural contract has been made with the London School of Hygiene and Tropical Medicine to investigate " conditions set up in domestic operations such as clothes washing."

It may be hoped that the instruction the Board has received to engage in " economic research " may bear fruit in the housing field. The standard which has been adopted for council housing in recent years has resulted in the accumulation of a local and national financial commitment which, under present circumstances, the country cannot afford to carry, and even with this heavy public subsidy the rents imposed are beyond the means of many people for whom the houses are intended. Some modification of building standards is to be made, but it is not clear that it will take advantage of a recommendation, made in the report, that the height of rooms should be reduced from 8 ft. to 7 ft. 6 in. A study carried out by the London School of Hygiene and Tropical Medicine has shown that such a reduction would have no ill-effect on health or comfort. This simple expedient, which would contribute towards the reduction of building costs, could be adopted to-morrow.

" Economic research," the other new factor in the extended field which the Board is now required to cover, involves two different, but interconnected, matters. One is the productivity of labour and the value, or otherwise, of incentive payment systems; the other is the investigation of new building methods and materials. On the first matter it is stated that a survey, covering 170 contracts, has been put in hand to examine the effect, both on productivity in man-hours per house and on costs per house, of the practice of sub-contracting portions of the work to specialist firms. This may possibly be found to be an important factor. In the United States, specialist firms, confining themselves strictly to one type of work, play a large part in the house-building field and have an important effect both on costs and speed of construction, particularly the latter. In this country, however, specialist firms of the American type do not exist in any significant number.

Alternative building methods, or new types of construction, have occupied the Board for some time, but under its extended responsibilities it will be able to take a more active part in the overall economics of such developments. In the past, a number of contracts were placed by the Ministry of Works for the construction of prefabricated houses, but in almost all cases the prefabrication was confined to the shell, and traditional fittings and components were used. The cost of the shell, or carcase, is, however, only about half the cost of a house, and an extensive programme is now to be carried out in which combinations of prefabricated internal components will be employed. A total of 440 houses is to be built, covering seven different combinations of shell and internal components. With the transfer of new responsibilities to the Board it is concerned with the preparation of drawings, specifications and erection schedules for this work.

Although house construction bulks so largely in public discussion on building matters it by no means represents the whole, or main, activity of the Building Research Station at Garston. Actually, the house-building studies appear to be carried out at a branch station near Boreham Wood and an office in Kensington. The report refers to the inconvenience of operating from three separate stations and expresses a hope that additional accommodation may be provided at Garston as soon as possible—a not unreasonable hope for a body engaged on building research. The range of work covered by the Board is indicated by the titles of the main sections into which the report is divided. These are : materials, design and performance of structures, soil mechanics, building operations, and efficiency of buildings and user requirements.

* *Report of the Building Research Board with the Report of the Director of Building Research for the Year* 1950. H.M. Stationery Office. [Price 4*s*. net.]

From an engineering point of view, the most important part of the section on materials is that concerned with cement and concrete. A detail research on cement and silicate chemistry is being carried out at Birkbeck College, and it is mentioned that the successful separation of minerals from blast-furnace slag has revived the hope that it may be possible to extract the main constituents of Portland cement for analysis and mineralogical study. Work on the interaction between Portland cement and aggregates has shown that none of the British aggregates so far examined is expansively reactive, as are some American aggregates. In view of the shortage of light-weight aggregates, other work is being directed towards the use of power-station clinker. The objection to the use of this material as an aggregate is that it usually contains a proportion of unburnt-fuel which may cause trouble in concrete. The work in hand, originally started by the Ministry of Works but now transferred to the Building Research Station, is concerned with cleaning methods and with the rapid assessment of the proportion of unburnt fuel present.

The section dealing with the design and performance of structures gives some information about an investigation of the deformation of, and stresses in, two test panels representing part of the road deck of the proposed Severn Bridge. The results of tests indicated that the design was generally satisfactory, but some minor modifications were suggested. Some results of tests on models of eccentrically-loaded concrete walls are also given. They showed that, with an initial eccentricity of $\frac{5}{12}$ of the wall thickness, for example, the strength of the wall was only about $12\frac{1}{2}$ per cent. of that when the loading was axial. With an eccentricity of this order, the concrete fails under tension. The report states that the extent to which tension can be resisted by the concrete of the plain wall is of particular interest and importance, since, for convenience, all tensile resistance of concrete is neglected in design. The conclusion has been reached, as a result of the tests, that the tensile resistance is a useful contribution to strength. The contribution to strength of the steel of the reinforced wall bears on this problem, of course. The test data obtained are serving as a basis of comparison for investigating the effect of this contribution, as well as forming a useful guide in designing plain walls and in assessing the uses to which these walls may be put in structural frames with small expenditure of steel.

Work on prestressed concrete and on steel wires marketed for use in prestressed concrete is also described in the section on structures. It was found that errors of as much as 5 per cent. might occur in the initial pre-tension if the wires were stretched in long lengths by an amount deduced from the stress-strain relationship obtained in tests on a short length of wire. It seems desirable, therefore, to measure the stretching force when pre-tensioning long wires.

The work on soil mechanics was largely concerned with laboratory investigations on the mechanical and physical properties of soils, but "on a limited number of occasions" it was found possible to carry out field tests on practical jobs. Previous work on the bearing capacity of piles in clay had shown that the bearing capacity was largely derived from skin friction, but field tests carried out with short bored *in-situ* concrete piles for house foundations suggested that the skin-friction obtained was much below that corresponding to the shear strength of the clay in its virgin condition. In the course of boring for piles, claystones are not infrequently encountered which prove a serious obstacle with hand boring. A simple proprietory tool consisting of a length of steel chisel driven by a sliding plunger was tried and proved successful down to a depth of 9 ft., which should be adequate for house foundations.

CORROSION OF BURIED METALS.

THE building of new towns and of large residential estates on the outskirts of London and other cities has created problems of the most diverse kind; some of these are quite outside the province of the technical man, but one problem which has come increasingly to the fore during the past two or three decades is that of the corrosion of buried iron and steel pipes and other metal structures. The problem is not, of course, new, but latterly the need for a solution or solutions to the difficulties involved have become more and more insistent, and much time and thought are being devoted to the subject in manufacturers' and users' laboratories and in research establishments in this country and elsewhere. A review of the present position and descriptions of some suggested remedies, several of which still appear to be of a somewhat interim or tentative nature, were given in the course of a "Symposium on the Corrosion of Buried Metals," held in London on December 12 under the chairmanship of Sir Charles Goodeve, O.B.E., F.R.S. The symposium was organised by the Iron and Steel Institute in conjunction with the British Iron and Steel Research Association and the Corrosion Group of the Society of Chemical Industry, but the six papers presented and discussed were all submitted by the Sub-Committee on the Corrosion of Buried Metals of the Metallurgy (General) Division of the British Iron and Steel Research Association.

In order to test the behaviour of cast-iron pipes and steel tubes buried in five representative soils in Great Britain, specimens in the form of 15-in. lengths of pipes, both bare and after receiving various protective coatings, were placed underground, five years ago, in most cases at a depth of 4 ft. 6 in. The five exposure sites were at Benfleet and Pitsea, Essex, at Rothamsted, Hertfordshire, at Gotham, Nottinghamshire, and at Corby, Northamptonshire. Several sets of the specimens were buried and one set has now been unearthed and examined. The investigators, Dr. J. C. Hudson and Mr. G. P. Acock, in their paper "Tests on the Corrosion of Buried Iron and Steel Pipes," emphasise that there is great variation between the soils at the various sites, but that, everywhere, the seamless-steel pipes suffered least pitting, and that, at most sites, the vertically-cast cast-iron pipes were the worst in this respect. When referring to coated specimens, the investigators are less explicit and add that a burial period of five years is too short to test the usefulness of many of the coatings. It appears, however, that a $\frac{1}{4}$-in. thick bitumen coating on steel tube and vitreous enamel on cast iron, have given excellent results; their surfaces are described as being almost perfect after removal from several of the sites. The tests are being continued.

In a paper on "Investigations on Underground Corrosion," by Mr. K. R. Butlin, Dr. W. H. J. Vernon and Mr. L. C. Whiskin, the authors refer at some length to work carried out at the Chemical Research Laboratory, Teddington, since 1934, on the part played by sulphate-reducing bacteria in promoting the corrosion of iron in waterlogged soils. In September, 1946, lengths of 4-in. diameter mains of spun cast-iron pipes were laid in wet clay soil at Chigwell, Essex. The first 118 yards were given the standard 0·005-in. coating by hot-dipping in coal tar; a further 118 yards were sheathed with $\frac{3}{8}$-in. bitumen; 60 yards were surrounded with 3 in. of Portland-cement concrete and 78 yards with 3 in. of aluminous-cement concrete; the final length of 61 yards was surrounded by 9 in. of gravel with no other special protective coating. After three years the pipes were examined and the hot-dip coal-tar coating was found to have given inadequate protection; the iron was pitted and attacked in other ways, while bacteriological examination showed the presence of numerous sulphate-reducing bacteria. On the other hand, the bitumen coating and the concrete and gravel surrounds appear to have afforded good protection to the pipe, but the investigators insist that a good quality of concrete must be used. It is proposed to make a further examination of the pipes at the end of another period of three years, namely, in 1952.

Two contributions to the symposium dealt with the cathodic protection of buried steel structures, the one was by Mr. K. A. Spencer and the other by Mr. R. de Brouwer, of Brussels. This is a relatively new protective method, as it was first mentioned about 1930 for underground pipelines, although similar methods for combating marine corrosion are older. Briefly, the pipeline to be protected constitutes the cathode and is connected with "sacrificial" anodes spaced at intervals and consisting of blocks of metal having a higher electrode potential than steel, such as magnesium, aluminium and zinc. An external direct current is supplied to the circuit and it is sometimes possible to use electric traction rails for this purpose. The total amount of current required to effect cathodic protection is directly proportional to the area of metal exposed; hence, the pipes are given tightly-adherent insulating coatings to reduce current consumption to a minimum, Mr. Spencer states that the current requirement is usually between 1 and 15 milliamperes per square foot of exposed metal; he adds that it may be even lower. The success of cathodic protection is evidenced by the fact that, in the United States, many hundreds of miles of natural-gas pipelines are protected by this method. Furthermore, at the meeting on December 12, the laying of, and application of cathodic protection to, an oil pipeline 57 miles in length across Scotland from Finnart on Loch Long, on the west coast, to Grangemouth on the Forth, was described, in some detail, by means of a sound film. Crude oil is discharged from deep-sea tankers at Finnart and conveyed through the pipeline to the refinery at Grangemouth.

Tests on the corrosion of buried copper, aluminium and lead were discussed in two papers presented at the symposium. One of the contributions, submitted by the British Electrical and Allied Industries Research Association, deals with earth electrodes in the form of buried copper or ferrous strips, plates, rods or pipes, and it is concluded that tinned copper is most resistant to corrosion, closely followed by copper, and that, in general, mild steel is given considerable protection, lasting at least 12 years, by galvanising. The other paper, by Dr. P. T. Gilbert and Mr. F. C. Porter of the British Non-Ferrous Metals Research Association, describes field experiments in which tubes 15 in. long and 1 in. in diameter, and sheets measuring 15 in. by 10 in. by $\frac{1}{8}$ in., of commercial-purity aluminium, phosphorus-deoxidised arsenical copper, and lead, were buried 2 ft. deep in trenches in five soils, comprising a salt marsh, London clay, moist neutral clay, Keuper marl, and cinders, respectively. After lying buried for five years, it was found that aluminium was severely attacked in four of the soils, particularly in the cinders, but was virtually unattacked in the moist neutral clay. Copper was severely attacked in the cinders, while the attack in the other four soils varied from practically nothing to a moderate localised attack. Lead was unattacked in the Keuper marl and moderately attacked in the other four soils; it behaved comparatively well in the cinders.

A broad general conclusion which, it seems, may be drawn is that, in so far as steel or cast-iron water, gas and other service mains are concerned, at all events, a coating of bitumen $\frac{1}{4}$ in. or $\frac{3}{8}$ in. thick should afford adequate protection in most circumstances in this country.

NOTES.

THE ROYAL INSTITUTION.

THE autumn series of evening discourses at the Royal Institution, Albemarle-street, London, W.1, was brought to a conclusion last Friday with a lecture by Professor E. N. da C. Andrade, F.R.S., Director of the Institution, on "The Mechanics of Metal Crystals." The lecturer began by explaining that the properties of metals were much more complex than those of liquids and gases because they depended, at any time, on the previous history of the particular specimen under examination. For example, pieces of steel of identical composition could be springy, flexible but inelastic, or brittle, according to the previous heat-treatment. A particular steel, which was non-magnetic, might be made magnetic by stretching it. Such differences were to be explained by differences in structure. The simplest way of beginning to understand the properties of a metal, he said, was to study the behaviour of specimens consisting of single crystals, although such specimens need not be whole crystals and could have any shape. Rods of metal consisting of a single crystal had remarkable properties. They were very soft and, when stretched, deformed by slipping along a series of planes so that their surfaces developed a succession of fine parallel steps. In some cases, such rods could be extended five-fold without breaking, although the process was always accompanied by hardening. Metals with a cubic crystalline structure, copper, silver and gold, for example, showed this tendency markedly and could become eighty times as resistant to deformation as in their original state. The peculiar properties of single crystals of a metal could be explained by the occurrence of small faults in their structure, called dislocations, which, under comparatively small stresses, initiated "avalanches" of crystalline disturbances. The minute crystals of ordinary metals contained such faults, but the run of disturbances was halted at the crystal boundaries; and this explained why the ordinary metal, contrary to theory and to expectation, was so much stronger than the single crystal. The behaviour of ordinary metals depended on the size of their crystal grains, the directions of the crystal axes of the grains—which might lie randomly or in preferred directions—the nature of the bounding surface—including the effect of oxide films which was often considerable—and, in the case of alloys, the distribution of the atoms of the different metals. The problems were very complex, but a beginning had been made on the work of solving them. A demonstration was given during the lecture of the production of an electric current in an iron wire on heating a short portion of the wire in a Bunsen flame and cooling an adjacent portion with solid carbon-dioxide. The lecturer also showed that a cadmium rod containing a trace of bismuth collapsed when boiling water was poured over it, whereas a rod of pure cadmium did not do so. A copper rod formed from a single crystal of the metal was shown to bend readily, but, afterwards, could be bent back only with difficulty, owing to hardening of the metal during the initial bending. A similar rod was shown to assume a flat elliptical cross-section on stretching.

GEAR LUBRICATION AND LUBRICANTS.

The Institute of Petroleum have announced that arrangements have been made for a symposium, at which papers will be read on the lubrication of gears and the testing of gear lubricants, to take place at Manson House, 26, Portland-place, London, W.1, on Wednesday, February 13, 1952. The first session will begin at 2.30 p.m., when a series of seven papers will be presented. Mr. A. Cameron, of Pametrada, will speak on hydrodynamic theory in gear lubrication, and Professor G. I. Finch and Dr. R. P. Spurr, of Imperial College, will follow with a discussion on gear-tooth wear. Dr. F. T. Barwell and Dr. A. A. Milne, of the Mechanical Engineering Research Organisation, will talk about criteria relevant to scuffing, and some factors affecting gear scuffing will be enumerated by Mr. H. D. Mansion, of the Motor Industry Research Association. The effect of the variations of viscosity with pressure on the load-carrying capacity of the oil film between gear teeth will be the subject of an address by Professor E. G. M'Ewan, of the University of Durham. Mr. E. A. Smith, of Acheson Colloids, Limited, will contribute a note on the performance of graphited oil, and Mr. R. Tourret and Mr. L. S. Evans, of Thornton Research Centre, will conclude the session with a paper on the wear and pitting of bronze discs run under conditions simulating a worm-gear drive. The second session, to be devoted to the testing of gear lubricants, begins at 5.30 p.m. At this, also, seven papers will be presented and these will deal with methods of testing, the interpretation of test results and their translation into practice, the selection and specification of gear lubricants, tests of vehicle lubricants in service, and kindred topics. The speakers include representatives of the Institute of Petroleum, research organisations, and industrial and transport undertakings. A limited number of preprints of all the papers will be available later at 1*s*. each, post free, to non-members of the Institute, on application to the secretary at the address given above.

THE INSTITUTION OF MECHANICAL ENGINEERS.

A general meeting of the Institution of Mechanical Engineers, arranged in conjunction with the Hydraulics Group of the Institution, was held at Storey's Gate, St. James's Park, London, S.W.1, on Friday, December 14, the chair being taken by the President, Mr. A. C. Hartley, C.B.E. Two papers were presented, namely, "Some Problems of Fluids for Hydraulic Power Transmission," by Mr. A. E. Bingham, M.I.Mech.E., and "Low Pressure Reciprocating Seals for Hydraulic Control Valves," by Mr. B. Cooke. Mr. Bingham, in his paper, emphasised that, fundamentally, the essential hydraulics of the air, the land, and the sea were similar, especially regarding the nature of the working fluid and the sealing problems. The ideal fluid that would suit all cases was still unknown, but it could be said that, practically speaking, it was only in the text-books that water persisted as the medium; it had been replaced mainly by the lighter types of mineral oil. The paper included a discussion and summary of the properties of a number of more or less well-known fluids, including those based on petroleum, castor oil, water-glycol, and halogenated and synthetic compounds. The properties reviewed included viscosity and density (and their variation with temperature and pressure), chemical and toxic effects, compressibility, miscibility with water, the significance of the cloud point, pour point and boiling point, and the weight to be attached to the fire hazard, to thermal conductivity and dielectric strength, and to problems of storage. Mr. Cooke's paper arose primarily out of the special considerations associated with the design of seals for hydraulic control valves on gun mountings, as Mr. Bingham's had done from the related, though distinct, questions involved in the design of aircraft landing gear. In tests on low-pressure seals, Mr. Cooke stated, the technique of designing a synthetic-rubber rotary seal of the lip type so that it was run-in on the shaft was applied to finishing the lip of a seal for a reciprocating application by first running it on a rotating shaft. The performance of a seal so treated was found to be greatly superior to that of untreated seals. The paper also contained a description of a test rig devised to measure the inward loading of a seal ring fitted with garter springs. By the use of this test rig, and by using spindles which were given, by wet grinding, a surface finish of only 6 micro-inches of roughness, it was found possible to maintain oiltightness under pressures varying from 1·3 lb. to 100 lb. per square inch for 23 million cycles. At the outset of the meeting, the President announced that the Council, at their monthly meeting earlier in the day, had conferred honorary membership of the Institution on Sir Henry Guy, C.B.E., F.R.S., the former secretary, who retired from that position at the end of 1950.

"LEGAL AID" AND STATE-OWNED INDUSTRIES.

Among the various Acts of Parliament passed by the previous Government with a view to turning this country into a welfare State, one of the most remarkable is that which enables certain members of the community to go to law at the expense of the taxpayer. Early this year we drew attention to some of the results of this extraordinary piece of legislation.* We then commented upon a case in which the grant of "legal aid" to a plaintiff resulted in a very serious loss to the defendant although, in fact, he won his case. Since that time, the Legal Aid Act has been before the Courts on many occasions, and eminent judges have constantly drawn attention to the need for its amendment. In a recent case (*Starkey* v. *Railway Executive*, reported in *The Times* of October 18), one judge made an attempt to abate its rigour, but, unfortunately, without success. In this instance, the plaintiff was injured owing to the movement of a train which started while she was in the act of alighting at a station. She recovered damages amounting to a substantial sum. Mr. Justice Stable, however, refused to give her costs because she was an "assisted person," his view being that, as a matter of principle, a plaintiff in receipt of legal aid could not recover costs from the unsuccessful defendant, but must recover them from the body financing the action. Leaving the provisions of the Legal Aid Act on one side for the moment, that is a decision which accords with justice and good sense. As we pointed out on the previous occasion, he who "maintains"—that is to say, provides—the means wherewith someone else can bring an action, was himself liable at common law to an action for damages. There was an appeal, however, on the question of costs. In the Court of Appeal it was pointed out that Sec. 1 (7) of the Act provides that "the rights conferred . . . on a person receiving aid shall not affect the rights or liabilities of other parties to the proceedings or the principles on which the discretion of any court or tribunal is normally exercised." It was stated in the Court of Appeal that the rule laid down by Mr. Justice Stable would mean that a wrongdoer would profit by the fact that a plaintiff was an assisted person and the burden which should fall on the wrongdoer would be transferred to the taxpayer; therefore the Railway Executive was made to pay the costs—the general rule being that the plaintiff who is successful in an action gets his costs from the defendant. But now we come upon an extraordinary effect of the Legal Aid Act. Normally, the costs of an assisted person are defrayed out of what is called the "Legal Aid Fund." That Fund, which is held by the Incorporated Law Society, derives from two sources. In the first place, assisted persons may be called upon to pay something to the Fund according to their means; but one who has no means need not pay anything. In the second place, the Fund is enriched out of moneys provided by Parliament, that is to say, out of the pocket of the taxpayer. If, then the decision of Mr. Justice Stable had been affirmed, those responsible for giving legal aid to the plaintiff would have been liable to pay the costs, presumably out of the Legal Aid Fund and, therefore, wholly out of the pocket of the taxpayer—if the plaintiff had made no contribution to the fund. The Court of Appeal, however, having said that the Railway Executive must pay the costs, the taxpaper will, in fact, pay them. The railways are the property of the State; their gains or losses are matters with which the taxpayer is all too closely concerned. Thus it is possible to enunciate the following extraordinary proposition: if a person who has been given legal aid brings an action against any one of the industries which have become nationalised, then, save possibly to the extent that the plaintiff has contributed to the legal aid fund (and he may not have been called upon to contribute anything), the taxpayer is liable to pay all the costs of both sides, whatever order the Court may make as to costs. It is fair to say, of course, that the "costs" of an assisted person are less than those of an ordinary litigant. Something is due to the charity of the lawyers who are content to do this service to the public at fees less than they can command in the open market.

BRITISH STANDARDS ABROAD.

The fact that British Standards are so often adopted by overseas countries is an indication of their technical merit. At home, factors other than the purely technical may enter into a decision to conform to a Standard, but industries abroad are

* ENGINEERING, vol. 171, page 348 (1951), "Employers and 'Legal Aid.'"

guided by a natural desire to benefit from the expression of authority and experience which the Standards represent. No fewer than 200,000 copies of British Standards—or roughly a quarter of the current annual distribution of over three-quarters of a million—go to Commonwealth and foreign countries. They are, in effect, "invisible exports," since more than half the 200,000 are taken by firms and government agencies who are active buyers in the world's markets. For many classes of goods and materials, adherence to the relevant British Standards is automatically accepted as sufficient warranty of quality and performance. Moreover, the appropriate B.S. number is often quoted in purchasing specifications and becomes part of the terms of contract. B.S. No. 218, for example, has recently been adopted by the South African Railways as their specification for brass bars, and the purchasing list issued by the Turkish State shipping organisation contains many references to British Standards as defining the kind and quality of goods required. In the Commonwealth countries, the influence is specially pronounced. Much of the work done by the independent standards bodies in Australia, Canada, India, New Zealand, Pakistan and South Africa is based directly on British Standards, and in many cases a particular specification, after review by a committee, is adopted as the local standard, either exactly as it is or with slight variations to meet local conditions. Full sets of British Standards are held for reference purposes by all standards organisations throughout the world, also by many universities and technical bodies, and by British Embassies and Legations, United Kingdom Trade Commissioners and representatives of the Crown Agents for the Colonies. In all, there are nearly 200 centres in 77 overseas countries where files of British Standards are kept up to date for reference.

SAFETY OF LIFE AT SEA.

The International Convention for the Safety of Life at Sea, which, it will be remembered, was drawn up at a conference held in London during 1948, will come into operation on November 19, 1952. The conference was attended by delegates from 30 countries and it was agreed that the convention they prepared should come into force one year after 15 countries, seven of which had not less than one million tons gross of shipping, had deposited their acceptances with the Government of the United Kingdom. This 15th acceptance was deposited on November 19, and the countries which have now accepted the convention are: the United Kingdom, New Zealand, the United States, France, the Netherlands, Sweden, Norway, South Africa, Iceland, Portugal, Canada, Pakistan, Denmark, Yugoslavia and Italy. When it comes into operation, the convention will replace that drawn up in London in 1929. In general, it makes no major change as regards the watertight sub-division of ships but lays down more comprehensive requirements in relation to fire protection and fire-fighting equipment, particularly on passenger ships. Rules to preserve the stability of passenger ships in damaged condition are laid down and all cargo ships, as well as passenger ships, must be inclined so that masters may be provided with stability information. So far as life-saving appliances are concerned, the main change is that the requirements will apply not only to passenger ships but to all cargo vessels of 500 tons gross and upwards. Ships in special trades that are not provided with lifeboats for all on board will, in future, have to comply with special sub-division requirements, and the use of radial davits in new ships and life-rafts in lieu of lifeboats is to be discontinued. Furthermore, every ship will have to carry a lifeboat, or lifeboats, fitted with radio, and all passenger and cargo ships over 1,600 tons gross will have to carry at least one motor boat or mechanically hand-propelled lifeboat. The new convention also provides that, in future, a continuous watch on the radio distress frequency, either by an operator or an automatic-alarm system, shall be maintained on all ships over 1,600 tons gross and that all vessels between 500 tons gross and 1,600 tons gross shall be fitted with either wireless-telegraphy or wireless-telephony The convention also lays down regulations for the carriage of grain and states certain broad principles for governing the carriage of dangerous goods.

LETTERS TO THE EDITOR.

DETERMINATION OF CRITICAL LOADS OF STRUTS.

TO THE EDITOR OF ENGINEERING.

SIR,—The letter by Professor Christopherson in your issue of November 16, on page 629, *ante*, proposing a modification of Sir Richard Southwell's ingenious method for the experimental determination of the critical load of a strut, was most interesting to me. The potentialities of Southwell's method for more complex cases have been investigated extensively by Donnell. An alternative and possibly more fundamental experimental approach is afforded, however, by studying natural vibrations.

The definition of the stable equilibrium of a system, that, given a small displacement from a position of stable equilibrium, the system will regain its initial condition, implies vibration about the equilibrium position. It is easy to verify this mathematically and such verification indicates that as the limit of stability is approached (i.e., the loading is increased) the appropriate natural frequency of the loaded system decreases until it is zero in the neutral condition at the stability limit. Further increase of load yields a mathematical result which indicates complete departure from the equilibrium position (i.e., buckling), as a result of a small displacement. The magnitude of the fundamental natural frequency of vibration of a loaded system in any mode is therefore a measure of its degree of stability in that mode, and, by varying the magnitude of the loading and plotting the square of the measured natural frequency, it should usually be possible to obtain the critical loading by extrapolation.

Yours faithfully,
T. M. CHARLTON.

21, Tynedale-gardens,
Stocksfield-on-Tyne,
Northumberland.
December 1, 1951.

PRELIMINARY INVESTIGATION OF HYDRAULIC LOCK.

TO THE EDITOR OF ENGINEERING.

SIR,—The letters from Mr. F. H. Towler and Mr. T. E. Beacham, in your issues of November 16 (page 630) and November 23 (page 660), respectively, put forward some interesting points in reference to hydraulic lock, and it is gratifying to know that the conclusions arising out of my research conform to the experiences of users of industrial hydraulic equipment.

I would agree with Mr. Towler in emphasising the importance of the method of producing the surfaces of the components. It appears to be the macroscopic surface finish (i.e., "waviness" or small dimensional deviations) which is responsible for the locking effect. The micro-finish (within the usual range for finished surfaces), I suggest, influences more the period required for build-up of the force, rather than its actual magnitude. Honing should certainly be capable of producing truer surfaces than cylindrical grinding.

Although the efficiency of the filtering arrangements, to which Mr. Beacham refers, was not checked this was considered to be adequate, and no indication of the trapping of dirt in the clearances was observed. Thus, over periods of the order of one or two hours, no perceptible decrease in the rate of oil leakage through the clearances occurred. Moreover, no variation in locking-force readings was observed during the course of the investigation, which could have been attributed to the effects of "muck lock" arising from increasing contamination of the oil.

The linear relationship between locking force and oil pressure is suggested as applying only up to medium pressures and with free components, as was the case in this investigation. Any constraint preventing free radial movement of a piston or valve spindle would obviously modify this relationship, and there may be a lower limit to the pressure at which lock could occur. It should, perhaps, be mentioned that the pistons employed by the writer were produced on an obsolete type of machine (since replaced, with the provision of new workshops), with the result that the surface irregularities were probably greater than might be expected from the use of modern equipment. This would account for the measurement of locking forces of appreciable magnitude at comparatively low oil pressures. For the purpose of these experiments this was, of course, in no way disadvantageous.

In reply to Mr. R. Hadekel, whose letter was published on page 660 in your issue of November 23, it is my opinion that surface irregularities are both the sufficient and necessary cause of pure hydraulic lock. With the arrangement shown in the drawing accompanying Mr. Hadekel's letter, the streamlines should be parallel. If any other distribution is postulated, it will be seen that the required axial and circumferential components of the pressure gradient are incompatible. Thus, in this drawing, the increased axial flow in the vicinity of the low-pressure end of the generator m will require a convex pressure curve, as shown; and along l a concave curve will be required. To produce the circumferential component of flow from l to m, however, at any transverse section there must be a falling pressure gradient from l to m. This, clearly, is not the case, and this type of flow distribution therefore cannot arise.

Yours faithfully,
D. C. SWEENEY.

Buswell & Sweeney, Limited,
Bolton-street, Bordesley,
Birmingham, 9.
December 4, 1951.

TESTS ON CONCRETE WITH ELECTRICAL-RESISTANCE STRAIN GAUGES.

TO THE EDITOR OF ENGINEERING.

SIR,—With reference to the letters from Mr. K. R. Peattie in your issues of October 12 (page 468), and November 9 (page 596), and our letter in the issue of October 26 (page 531), we now wish to make the following points concerning the nature of the strain distribution along a longitudinal strip of a concrete cylinder undergoing axial compression.

We read with interest Mr. Peattie's second letter, in which he states that the end constraint caused by the friction between the loading platens and the caps of the specimen prevents the ends of the generators of the cylinder from being normal to the face of the platens. We beg to differ. Consider the method by which the cylinder is loaded. As Mr. Petttie correctly stated, the lateral constraint is produced by the friction force acting radially inwards that is developed between the loading platen and the cap of the cylinder. Considering the behaviour of the cylinder under this frictional loading alone, the caps are under a shearing force, but the intensity of this force, i.e., the shearing stress, varies with the radius, being zero at the axis and at the outer surface of the cylinder. There will be no shear stress at the axis because of the symmetry of loading. Elsewhere this horizontal shear stress is accompanied by a complementary vertical shear stress. At the periphery we have a free surface, so that the vertical shear stress must be zero and hence the horizontal shear stress will be zero. It follows then that, as the caps of the specimen are constrained to remain plane by the loading platens, the ends of the generators of the cylinder must remain normal to the platens.

The effect of the complementary vertical shear stress is that the central core of material is put into a state of axial compression while, for equilibrium, the outer material must be under an axial tensile stress. This causes sections which were plane before loading to become dished. Hence, if the loading face of the platen is a plane surface, when a cylinder is put into axial compression the loading pressure will be greatest at the periphery. The effect of this will be to induce radial tensile and compressive stresses within the cylinder, but these will be zero at the outer free surface.

The effect of the radial shear stress at the ends is to cause a hoop compressive stress in the concrete. The resulting hoop compressive strain will be accompanied by an axial tensile strain which will be greatest near to the caps. When this is superimposed on the uniform axial compressive strain, the effect will be a compressive strain which reduces slightly towards the caps from the maximum which occurs at the mid-height. The variation will be small, however, if only because of the small value of Poisson's ratio for concrete. For example, if we consider that the end friction is such that there is no movement at the caps, and at the mid-height of the cylinder the effect of end friction is negligible, then, if there is a mean axial compressive strain in the cylinder of e, the hoop compressive strain due to friction will, at the ends, be σe. The axial tensile strain at the ends will then be $\sigma^2 e$, so that, if Poisson's ratio σ for concrete is, say, $0 \cdot 14$, then the uniform compressive strain along the surface due to the compressive loading alone will be reduced at the ends by 2 per cent. The compressive strain distribution along a longitudinal strip will therefore be "practically uniform."

We reiterate our assertion that it is possible for the hoop strain at the mid-height of the specimen to be five times that near to the ends, as was observed in our tests, while at the same time the axial compressive strain is found to be practically uniform. The ratio between the hoop strains will, of course, depend on the amount of the end constraint.

The estimate of a 2 per cent. increase in the effective modulus for concrete near to the ends of the specimen, which we gave in our letter, was admittedly based on a type of loading to which a compression cylinder is not subjected. The 2 per cent., however, was given as the maximum possible increase in the effective modulus; on further reflection we feel that the hoop compressive stress induced in a block of material by shear alone could possibly give rise to a somewhat greater increase, but we still maintain that 2 per cent. is of the right order.

Mr. Peattie, in reply to our letter wherein we requested an explanation of what was happening to the ends of his specimen, instead attempted to describe the behaviour of an ideal cylinder. Unfortunately, it seems from the results given in the graphs which accompanied his first letter (October 12, page 468), that the specimen used in his tests was far from ideal. Examination of his graphs shows that, taking the modulus of elasticity for the concrete over the load range from 12 to 24 tons, the modulus at one sixth of the height from the ends is approximately 18 per cent. higher at one end, and 61 per cent. higher at the other end, than at the mid-height of the cylinder. As we have explained above, the greatest applied compressive pressure in an ideal cylinder is at the periphery, and then the axial compressive strain is practically uniform along the length. It seems probable then that in his experiments he was not applying the greatest pressure at the periphery of the cap. We believe, in fact, that Mr. Peattie's specimen was domed at the ends. Such a specimen would suffer small, or even zero, axial strains near the ends of the generators, as he found. In addition, we believe that the eccentricity of the domes was different at each end of the cylinder, thus causing the asymmetry of his results.

The doming may have been caused when rubbing down the plaster of Paris caps. Alternatively, it may have been due to the caps drying out to a greater extent at the rims than at the centre, resulting in more shrinkage at the edges. The condition of his tests, without packing, would fully reflect these shortcomings in his specimen, whereas the use of a "soft" packing would probably have obscured the defect. The applied load would then have been more uniformly distributed over the caps and so would have approached the condition of a fluid pressure which is essential for the ideal compression test.

His explanation that the lack of symmetry was due to a variable concrete was probably only a secondary effect. We cannot believe that Mr. Peattie would use, for a scientific investigation, a test specimen of such variable quality concrete as would give rise to the results quoted. We believe, therefore, that it was the deformity of his specimen and the condition of loading which prevented Mr. Peattie from measuring an axial strain distribution which was uniform within the limits of experimental accuracy.

In conclusion, we are indebted to Professor A. N. Black for his observations on these matters.

Yours faithfully,
N. S. J. GRASSAM,
Lecturer in Mechanical Engineering.
University College, Southampton.

DAVID FISHER,
Civil Engineer.

32, Sandringham-road,
London, N.W.11.
December 8, 1951.

THE CONSTANTINESCO FIRE CONTROL.

TO THE EDITOR OF ENGINEERING.

SIR,—My attention has been called to an article in your issue of November 9, 1951, on page 603, *ante*, entitled "Institution of Mechanical Engineers: Presidential Address," by A. C. Hartley, C.B.E., B.Sc. (Eng.), M.I.Mech.E. The speaker rightly stressed the importance of imagination, but even imagination must take some account of recorded facts. My name is mentioned in the presidential address, in which I am awarded the rather ambiguous compliment of being the originator of a "really silly idea" which I am supposed to have thrown into the deliberations of a department struggling with a desperate problem, just after another gentleman "had been disposed of" because he wanted to attach refrigerating machines to kite balloons supporting frozen airfields in the clouds . . .

To come now to earth, as far as I am concerned my work and myself have also apparently been "disposed of" without further ado after the related encounter between a harassed department and two lunatics. When that event took place and where is a mystery to me, but, in any case, it could not have happened before September 12, 1916, which is the precise date when Mr. Hartley for the first time came into contact with me and my work.

However, the C.C. Gear, or to give it its full name, the "Constantinesco Fire Control" was by then already invented, developed and patented by me. My specific British Patent No. 128,592, lodged on July 14, 1916, includes the theory, full description and detailed illustrations of the invention. Figs. 9, 10 and 11 clearly illustrate the reflected-wave perforated valve absorber and four-to-one sharp impulse generator. This specific patent is a particular application of the more comprehensive invention of mine, British Patent No. 128,589, which also has a full description and theory of the reflected-wave absorber and sharp impulse generation, both fully illustrated in Fig. 4. These valuable patents, which completely cover all the essentials described in Mr. Hartley's address, were granted to me and not to Mr. Hartley or his team.

A further proof, if need be, that my ideas were not "really silly" at the time I met Mr. Hartley is the fact that the British and American Governments recognised the merits and the validity of these specific patents and paid 215,000*l*. royalties for their use.

Before the Royal Commission on Awards to Inventors (March 20, 1923) Mr. Trevor Watson, Counsel for the Crown, stated frankly: "Undoubtedly one of the great inventions of the century." Before the same Commission, after my Counsel had explained the method of preventing reflected waves described and illustrated in my patents, the chairman remarked: "You have told us quite enough to make us appreciate the extraordinary ingenuity of the invention." In *The Times* of March 29, 1920, one can read the following remark made by a gallant officer: "Air Vice-Marshal Sir John Maitland presided on Saturday at a lecture by Mr. G. Constantinesco on 'Sonics' (the transmission of power by sound or vibrations). Sir John said it was very greatly due to Mr. Constantinesco and the gear which he invented for operating machine guns in aeroplanes that we held the supremacy over the Germans in the air as we did."

I hope that this correspondence will be published in your paper so as to bring home to Government departments not only the necessity to fire the imagination of their officers, but also promptly to extinguish it when it runs riot into the preserves of hard-working inventors.

Yours faithfully,
G. CONSTANTINESCO.

Oxen House,
Torver, Coniston, Lancashire.
December 10, 1951.

[In fairness to Mr. Hartley, we would point out that what he said was that "To many the idea would have at first appeared silly"—as did the first iron barges to shipwrights accustomed to wood, and steam navigation to seamen used only to sails. That is not to say that Mr. Hartley or his associates themselves thought that it was silly.—ED., E.]

SOME UNKNOWNS IN GEAR DESIGN.

TO THE EDITOR OF ENGINEERING.

SIR,—A remark in Dr. H. E. Merritt's paper on this subject (pages 734 and 763 in your issues of December 7 and 14, respectively) suggests that one important point in connection with permissible loading of gear teeth needs stating clearly and concisely.

Gear tooth stresses induced by the combined effect of speed and error ("dynamic stresses") do not depend in any way upon the mean torque transmitted by the gears or upon the permissible torque at zero speed. Dynamic stress in a given pair of gears at a given speed defines a difference between the applied torque permissible at that speed and the applied torque permissible at zero speed. The practice of multiplying the permissible torque at zero speed by a "speed factor," in order to determine the permissible torque at a certain speed, assumes that the ratio of the dynamic effect of speed and error to the permissible torque at zero speed is determinable from the speed concerned. The speed factor is thus quite irrational, but, nevertheless, a great deal of time and effort has been expended in trying to force facts to comply with that concept. The speed factor has been a feature of British Standard gear rating for nearly 20 years and great resistance to its supersession is to be expected.

The Hertz expression for surface stress induced by line loading indicates that permissible line loading should be proportional to the relative radius of curvature (R_r) of the surfaces, but this was not found to be the case in practice when the effect of speed was assessed by rotational speed instead of pitch-circle speed and was taken into account by a factor instead of a subtraction. As it happened, this irrationality could be roughly balanced over normal ranges of size and speed by making allowable load proportional to $R_r^{0 \cdot 8}$, and this second irrationality was excused by saying that perhaps it had something to do with the oil. In the reply to the discussion on my paper on "Gear Tooth Stresses at High Speed" (*Proc. I. Mech. E.*, 1950, vol. 163), I outline a method of estimating gear life that involves no speed factor and agrees more closely with actual experience than does the British Standard rating formula.

The early British Standard Specifications on gearing were irrationally based in almost every respect, but the work of enlarged and more critical committees has kept the obvious absurdities out of the later editions. Nevertheless, the imperfections are still such that not everyone who has contributed to the specifications will insist on claiming that he did so, and there is justification for a fundamental revision. The British Standard Specifications have unnecessarily taken on the character of a somewhat academic text-book, and a much simpler and more useful form can be devised by starting afresh on practical lines. There is no difficulty about this, once it is understood that, whilst the age of the present system may command respect, there is little in its quality to do so. It is true that there are, and probably always will be, unknowns in design of gears (and of other things), but the greatest practical need is not to brood upon the fact, but to make the best use of the knowns. This may be encouraged by presenting them with direct simplicity rather than in the devious ways prescribed by compliance with elaborate convention.

Yours faithfully,
W. A. TUPLIN,
Professor of Applied Mechanics.
University of Sheffield,
December 15, 1951.

INTERNATIONAL CONFERENCE ON ABRASION AND WEAR.

(*Continued from page* 760.)

THE two papers presented and discussed in the afternoon session of the International Conference on Abrasion and Wear, at Delft, Holland, on November 15, were by Mr. J. M. Buist, who dealt with "Abrasion and Wear of Rubber," and by Dr. R. D. Stiehler, whose subject was "Some Factors Influencing the Road Wear of Tyres."

ABRASION AND WEAR OF RUBBER.

Mr. Buist observed that, while numerous laboratory tests had been designed to measure the abrasion resistance of rubber, the correlation with service applications was "atrociously poor." Where rubber was subjected to wear (e.g., in tyres, soles and heels, and proofed rubber garments) great care had to be exercised in planning the service tests and in making the actual measurements. The analysis and interpretation of wear data from service and laboratory tests presented certain difficulties; for example, results were often expressed either as a loss after a fixed time or as the ratio of the loss of a compound to that of a standard compound, and both methods had defects. If ratings for two compounds were calculated at progressive stages in a wear test, the rating obtained was not constant, but varied according to the stage reached in the wear curves. This immediately raised an objection to laboratory abrasion tests, in which compounds were normally evaluated for a fixed time. As wear curves were available from service data, it was more logical to measure the wear curve in the laboratory test and to compare the full wear curves in both cases.

Some years ago, Mr. Buist continued, he had found that wear curves obtained in the Martindale abrasion test could be described by an empirical equation of the power-law type, $y = ax^n$. He proceeded to show that wear curves for a wide range of compounds, tested on a variety of laboratory machines, e.g., the Du Pont, and the Dunlop (Lambourn), were all of the same family; so also were those from service data (such as the road wear of tyres) and there was reason to believe that data from tests of soles and heels could be expressed similarly. The fact that that empirical equation had such a wide application in the wear-testing of rubber, in the laboratory and in service, was of interest and importance. By using that method, it was possible to construct wear curves from measurements made in the initial stages of wear; and, having calculated the constants in the equation for different compounds, to calculate what the wear would be in subsequent stages. Examples were given in the paper. By using that technique with one laboratory test, a saving of time in the testing schedule of 75 per cent. was achieved. Service tests were more expensive than laboratory tests, so that any such reduction in service tests was correspondingly more valuable. With most laboratory tests, the index n was greater than unity, whereas in the road tests n was less than unity; and he suggested that the rate of wear should decrease in both cases as the test progressed, if a true comparison was to be made. In conclusion, Mr. Buist discussed the effect of various factors on the values obtained for n, and showed how curves of the rate of wear could be interpreted; but, he said, the errors in rubber testing were large and the causes often unknown. Much reliance was placed on statistics, but, even so, he considered that, in general, statistically planned experiments were not sufficiently used in the rubber industry.

The discussion was opened by Mr. D. J. van Wijk, who said that abrasion tests had been in use for about 50 years and, with some types of apparatus, he thought that there was a fair correlation of laboratory tests with practice. The best that could be expected was, for each type of abrasion, to find a test apparatus that would give a good correlation in similar circumstances; but even yet no one knew exactly what abrasion was. Dr. Buist, in his paper, had shown one way towards a solution, and Mr. van Wijk agreed that temperature was an important factor. He was convinced that the time had come to make a fresh start in another direction and to try to find which fundamental properties of the material were related to the phenomena of abrasion. Therefore, it was necessary to study the effect of temperature, as Dr. Bowden had indicated; to make morphological studies, such as Dr. Salomon and Dr. Schallamach had referred to; and to study the rheological behaviour of materials. That, in his opinion, was the only way to get somewhat nearer to the causes of abrasion.

Mr. E. de Meeus suggested that, if the empirical power-law correlation was to become widely useful the nature of the samples used in the laboratory, apparatus was also important; at present, one cause of difference between laboratory and service tests might be the differences between the processes of manufacture of the test-pieces. Laboratory samples were moulded in a reasonably warm flat mould, from blanks of the same shape and size as the vulcanised slab, whereas the tyre treads used in service tests were set directly in hot moulds, causing an over-cured condition of the surface and severe internal stresses, resulting from the numerous protruding parts of the mould. He asked what method Mr. Buist would consider desirable for a test-piece intended for use in the Martindale type of testing machine.

Dr. W. Späth said that it was the general practice to measure resistance to abrasion by the time to ultimate failure, as was done in measuring the service life of machines, rails, etc.; or, alternatively, to define abrasion in a reciprocal way by the number of pieces worn down in a given time. By systematic consideration of such equivalents, many advantages were to be gained, which he illustrated by examples of the life of tyres in service in relation to the load and temperature, for a speed of 60 km. per hour. The life was seen to increase considerably with decreasing load. A second family of curves was obtained from the relative rates of abrasive wear and, by extrapolation, a critical load was found, below which the abrasion was negligibly small. Above the critical load, the rate of increased wear was almost linear at first, and afterwards accelerated. He showed similar examples relating to the wear of cutting tools and the effect of dynamic fatigue tests, made with light alloys.

Mr. P. Braber said that there was a risk, in the use of log. log. plotting, of giving the impression that everything lay on straight lines. He thought that the power-law equation provided a sound basis for future research. The work done at the Rubber Stichting with a Tabor abrader, using different materials, gave values of $a = 1 \cdot 82$ and $n = 0 \cdot 612$ to $0 \cdot 653$; the material tested contained only 25 per cent. of rubber, being intended for flooring. The Du Pont machine could be used with constant load, constant torque, or, perhaps, constant energy input, and he asked what values of a and n Mr. Buist would expect under those conditions.

Dr. A. Schallamach agreed with Mr. Buist that laboratory tests of abrasion were often taken too quickly; before pieces of rubber were torn off, they had undergone serious deformation. He thought that some of the discrepancies between laboratory and road tests were due to tearing the material too soon in the laboratory.

Mr. Buist, in reply to the discussion, agreed generally with Mr. van Wijk on the need for fundamental work; for example, much more was necessary on friction and temperature. While the fundamental work was in progress, however, the proposed empirical approach could be useful. The questions of over-cure on the surface of a laboratory test-piece, and of the whole preparation of test-pieces, raised by Mr. de Meeus, were undoubtedly important; but, if the test-pieces were "run in," the surface skin was removed, as it was with actual tyres, in the early stages of the wear curve. Measurements of the wear at such early stages were erratic in the laboratory and in service, and were not generally used. Dr. Späth had discussed metals rather than rubber, and metals were more amenable to controlled experiments; but Mr. Buist felt that, in the case of rubber, the rate of wear was the true measure of abrasion resistance, which appeared to agree with Dr. Späth's view.

Mr. Buist's paper aroused considerable discussion among the members of the Conference, several of whom subsequently added written contributions to it. Among these was one from Dr. J. R. Scott, who commented that, in laboratory abrasion tests, the stress distribution in the test-piece changed as the specimen wore down, because the wearing surface came nearer to the point where the test-piece was held. This, he suggested, was probably one reason why n differed from unity. To remove that cause, tests should be made with a special test-piece holder which would allow the amount that projected from the holder to be kept constant.

Mr. Buist replied that it would be interesting to use such a holder as Dr. Scott had proposed. Equally, the reason why n differed from unity in service might be the change in the geometry of the surface of a tyre, and the change in the properties of the rubber throughout the thickness of the tread. Finally, attention should be drawn to the regression equations relating wear and abrasion to the physical properties of the rubber: the Du Pont abrasion figure was $766 - (5 \cdot 341 \times \text{Shore hardness}) - (1 \cdot 039 \times \text{tension strength})$; and the wear index equalled $331 \cdot 8 - (0 \cdot 808 \times \text{hardness}) - (1 \cdot 510 \times \text{breaking stress})$. It would be noted that tear strength was not included in those equations; in fact, when it was included, no improvement in correlation resulted. Therefore, although common-sense indicated that tear properties might be important, tear as measured in the laboratory at present did not help the correlation. The limitations and the usefulness of the equations had been discussed at Birmingham a year ago [*Trans. I.R.I.*, vol. 26, page 192, 1950].

Dr. A. J. Staverman, in a note communicated after the session, pointed out that the law, $y = a\,x^n$, could not hold, for physical reasons, for very small values of y; therefore it seemed better to use, as a general formula, $y = a\,x + b\,x^2$, which, unlike the previous law, might continue to hold when measurements became more accurate. For the comparison of data under various conditions, the second of those equations was superior to the first, because it contained a main term and a correction term. It was also to be preferred because of the dimensions of the quantitites.

In reply to Dr. Staverman, Mr. Buist agreed that $y = a\,x^n$ did not fit the wear curve very well in the early stages. He repeated, however, that the very early part of the curve had little practical importance. Table I in his paper showed that the fit at 1,000 r.p.m. with the Martindale test was good. Other results showed a reasonable fit at 500 to 750 r.p.m., but the results at 250 r.p.m. seldom fitted the curve. He had considered the general equation of the type proposed by Dr. Staverman; but it was not so easy to apply and, as he did think that greater accuracy in the early part of the curve was ever required, he did not use that method.

Professor F. P. Malschaert wrote that, if n varied, it meant that the conditions had varied during the test. If a_1 and n_1 were derived from a service test, and a_2 and n_2 from a laboratory test on the same materials, no correlation between the service test and the laboratory test could be expected if a_1 differed from a_2 and n_1 from n_2. The probability of a reasonable correlation did exist if a_1 equalled a_2 and n_1 equalled n_2. Of course, y and x should be measured in suitable units. Laboratory tests should always be adapted to service tests and not *vice versa*; but service tests should be well defined and agreed upon, which was a difficult problem, requiring statistical methods and a careful screening of results. All that had been known for half a century; he repeated it with the sole purpose of pointing out why, in his opinion, the problem of abrasion and wear was so complicated, and why no individual effort, however ingenious and patient, had a sporting chance of solving it.

Mr. Buist agreed with Professor Malschaert about the difficulties of correlating laboratory and service tests, but thought that the procedure outlined in the paper was a useful approach to ensuring that the conditions of test were such that there was more chance to obtain good correlation between laboratory and service. During the symposium, Mr. Buist added, various references had been made to the "Mullins effect." Mr. L. Mullins had shown* that, on subsequent stressing, the stress developed for a given strain was always less than on a first stretching; that conclusion, Mr. Buist emphasised, was based on work done under conditions of constant strain and did not present an entirely accurate picture, as Mullins's conclusion was only true if the energy input was small. It was possible to show that, with high energy inputs, the stress was higher with subsequent stretches than on the initial stretch; indeed, at intermediate energy inputs, it was possible for the stretch to remain practically constant with subsequent stretching. That fact had been checked experimentally, both on a conventional tensile testing machine and by measuring the stresses developed under impact with different energy inputs. In the case of higher energy inputs, a steeper gradient of the stress/strain curve at the higher elongations and the subsequent deformations suggested that a greater degree of crystallisation and/or alignment could be produced by the same energy input after the initial filler structure had been broken down.† Clearly, the whole of the phenomena required much closer study, and must be described accurately by indicating the conditions under which the test was done; in his view, therefore, it was quite misleading to refer to part of the phenomena as "the Mullins effect."

The concluding paper in the programme of the Conference was that of Dr. R. D. Stiehler, Mr. M. N. Steel and Mr. J. Mandel on "Some Factors Influencing the Road Wear of Tyres."

FACTORS INFLUENCING ROAD WEAR OF TYRES.

In the abrasion of rubber, said Dr. Stiehler, three types could be distinguished, namely, abrasion by impact, as in sandblast hose, for which tyre compounds were of no use; cutting abrasion, as in the case of tyres on sharp stones (for example, the examples illustrated by Dr. Schallamach in his paper); and abrasion by friction, which was the normal abrasion of tyres on roads, and which Dr. Stiehler thought to be definitely a chemical process. Three road tests of tyres had been designed statistically to equalise the treatment of tyres. Some of the factors influencing road wear which were included for study were the effects of the vehicle, the wheel position, the day of the test, the climatic conditions, and the length of time that the tyre had been in store. A study was also made of two methods of measuring the depth of the tread grooves and the loss of weight. It was found that a tyre lost weight at what was essentially a constant rate, whereas the depth of the tread grooves decreased at a declining rate, resulting in a bias in the tread-wear ratings. The weight method was found to be more sensitive than the depth method; the study of the effect of vehicle and wheel positions led to the conclusion that differences in the rate of wear on different wheels did not affect the tread-wear comparisons, since the rate in slow-wearing positions was proportional to that in fast-wearing positions, the coefficient of variation being about the same. The conclusion was reached that geometrical rather than arithmetical averages should be used in evaluating tread wear. It was found that the surface temperature of the road and of the tyre had a pronounced effect on the rate of wear. In tyres which had been run on the road, there was a great increase in the percentage of carbon black in the surface, perhaps because the rubber had been burnt away. Natural-rubber treads containing channel black wore faster as the temperature increased, whereas synthetic-rubber treads, containing furnace blacks, wore faster as the temperature decreased. Other types of tread wore at almost a uniform rate as the temperature changed. The effect of temperature on tread wear was often greater than the effect of a lower coefficient of friction on wet roads. Lack of alignment of wheels produced some interesting results: if, in a laboratory test, the wheel ran in line, the temperature reached was about 100 deg. C. and the power absorbed was 5 h.p.; while, if the test wheel was turned $2\frac{1}{2}$ deg. out of line, the temperature remained the same but the power went up to 10 h.p. In other words, 5 h.p. was being expended in wearing the surface.

The object of one test, Dr. Stiehler continued, was to determine the effect of rubber and black on tyre wear; it was found that the rubber and black were mutually independent in their effects. The behaviour of natural and synthetic rubbers, or of channel and furnace blacks, with change of temperature made it impossible to compare them without stating the conditions of test. In 1952, the United States Government would be buying 50 million dollars worth of tyres, and to ensure a uniformly good standard of production over such a large quantity, statistical methods of control were essential. The United States Bureau of Standards [with which Dr. Stiehler is connected—ED., E.] had tested 41 tyre compounds, using a whole tread of the compound in each case. Tests of the rate of tyre wear by weight showed that the power-law equation could be misleading. In a typical road test, using four vehicles, it was found that, on passenger cars, the front tyres wore faster than the rear tyres; but in corresponding tests with truck tyres, the rear tyres wore more quickly than the front. The trucks were run loaded.

Mr. P. Braber opened the discussion. The Rubber Stichting, he said, was also investigating tyre wear, but, having no test fleet of vehicles, had to make use of those in normal public and private use, by arrangement with the owners. Dr. Stiehler had said that measurement of loss of weight was preferable to skid loss, as a tyre lost weight more or less uniformly, whereas the depth of grooves in the tyre pattern decreased at a declining rate; how did he account for the varying rate of tread loss when the only variable factor appeared to be the area in contact with the road as the tyre became worn? At the Rubber Stichting, in comparing the abrasion resistance of different compounds, they had concluded that measuring wear by the depth of the grooves, which was by far the simpler method, had definite advantages.

Mr. G. Bielstein said that he saw no *a priori* reason to reject depth measurements on account of statistical difficulties arising from the changing rate of wear. The theoretical life of a tyre usually had to be calculated from very incomplete data, and, though it might be simpler to do so with weight measurements, the result should be just as accurate when obtained from depth measurements by means of an empirical law, such as that proposed by Mr. J. M. Buist. Bearing those points in mind, it was important to decide whether the definition of tyre wear should relate to the tyre as a whole, or merely and specifically to the loss of the tyre compound. From the paper, it appeared that the loss deduced from depth measurements could only refer to the whole tyre—at least, until the tread had worn away—whereas it was stated that the loss deduced from weight measurements did not take account of the design of the tread. Did this imply that the weight measurements related only to the rubber compound; and, if so, should future laboratory experiments aim to reproduce service data obtained by weighing rather than by depth measurements?

Mr. F. Hesselink observed that, in the investigations described, only homogeneous material had been tested; but if it was desired to evolve a formula for wear as a function of various factors including that of hardness, it would not suffice to use only one hardness, because the hardness of the surface layer must be different from that of the material beneath if the structure or material was to have a good wear resistance. In bearings, the best practice used a layer of soft metal on a hard base. An example of good wearing properties of a material with a hard surface on a soft subtratum was human skin. The tread pattern on tyres shifted more of the elastic movement to the substratum, which had the same effect as using a softer substratum. In general, he suggested, the use of hardness as a characteristic value for test-pieces was of doubtful validity; even the smallest test-piece might well be a structure of hard and soft material.

(*To be continued.*)

* L. Mullins, *Jl. Rubber Res.*, vol. 16, page 275, (1947).
† J. M. Buist, *et al.*, *Ind. Eng. Chem.*, vol. 43, page 373 (1951).

THE UNIVERSITY AND THE CIVIL ENGINEER OF THE FUTURE.*

By PROFESSOR J. B. B. OWEN, D.Sc.

THE University of Liverpool, in creating a Chair of Civil Engineering in 1908, was to the fore in recognising that the breadth of engineering studies could only be covered adequately by specialist schools. In recent years, considerable concern has been continually expressed regarding technical education in this country, and it seemed to me appropriate to glance at what we have done and try to grasp some of the problems that lie ahead if the university is to maintain its traditional leadership.

While my predecessors played their part in the development at the university of the whole man, they endeavoured to give their instruction a pre-eminently practical bias, and I think I would be expressing the view of a large number of engineers if I said that we had little time for anything for which we saw in our imagination no ultimate use. To us, as to Chekhov, "everything should be beautiful in a human being . . . and an idle," useless "life cannot be a good one." Utility (with or without the Government stamp) is the key to unlock the door through which to get ideas across to engineers, and I hope the university will exploit this access in making its contribution to civil engineering of the future.

The cries raised by those concerned about technical education have been for more and better engineers, more postgraduate courses, more co-operation between scientists and engineers, less emphasis on fundamental long-term research, and more on the application of what we already know. While I do not consider that expediency should deter us from doing what we consider proper, we might pause for a moment to see whether these cries have a bearing on what this University should do for civil engineers.

The Barlow Committee recommended that the universities should double their numbers in ten years. The universities have roughly doubled their pre-war output of civil engineers in five years. G. A. Maunsell, in his James Forrest Lecture in October,† reminded us that many major works are outstanding, but the Hankey report of September last, though finding some difficulty in coming to a decision, considers that the present output of civil engineers is likely to be sufficient for the next five or ten years. The universities have then accomplished, more rapidly than envisaged, what was suggested as desirable, and this without a fall in degree standard. This provides a healthy basis for the cry of better civil engineers.

We always want something better, and we are in an age of rapid change and development. Examples of this can be seen in road developments in America, the use of bitumen in hydraulic works in Holland, the buildings of the 1951 South Bank Exhibition, etc. In this country, prestressed concrete is now very fashionable. Its success can be attributed to the high price and shortage of steel, the use of steel of higher strength than is customary in orthodox steel structures, and to the use of better quality concrete than is usual. This has enabled light prestressed concrete parts to be made, and pre-casting, under close factory control, to be used extensively.

Even in house construction the advantage of light-weight bricks is becoming appreciated, and I can see light-section high-tensile steel and aluminium structures stabilised by light-weight expanded materials coming to compete with prestressed concrete and other forms of construction. Considerable advances are also being made in the understanding of how to proportion structures; for example, E. H. Mansfield has recently shown that, if the boundaries of suitably reinforced holes in a stressed plate were given by $\phi + ax + by + c = 0$, where ϕ is Airey's stress function, then the state of stress in the plate remains undisturbed.

How is the university to cope with all the variations in design which are possible? In my view, it can do this only by providing its students with a firm grasp of the underlying principles. What we do will depend largely on our view of what civil engineering is. I consider it to be an art based on scientific principles—the art of using the resources of Nature for the betterment of mankind: an art and a science. The civil engineer is more than a mere technologist. On this account, I would modify the cry for "more co-operation between the scientist and the engineer," to more co-operation between the engineers, the scientists and those nurtured in the humanities.

It is not sufficient to have a technical solution of a scheme which ignores its impact on human society, or satisfactory to depend on powers of coercion to drive a labour force on to complete a project. Instruction in management might help, but, in my view, much

* Inaugural public lecture given at the University of Liverpool on December 7, 1951. Abridged.
* See ENGINEERING, vol. 171, page 699, 737, and 768 (1951).

better results would be achieved if the student organisation could be such that, except when studying engineering, the student found himself among those from other faculties, and he had more leisure which he used in non-technical activities.

The basic training of the science graduate often fits him very well to push forward the technical frontiers of civil engineering, and to replace empiricism with a real understanding of the subject. His assimilation into the civil engineering profession needs, however, in some cases, a change of attitude of mind. The art of civil engineering is partly the art of making the right approximation, of knowing when meticulous accuracy is not required and when it is essential. This change of attitude can be brought about, perhaps, by the science graduate spending an extra year at the university in tackling an engineering research problem, or it may be achieved by his going out to practical work in engineering and then returning to the university when he has appreciated the nature of the practical problems involved. The task of improving the civil engineer turned out by the university involves keeping the basic instruction up to date and introducing or extending suitable postgraduate courses and research work.

The undergraduate course in engineering is already so full that no attempt should be made to introduce anything more without leaving out something which is included at present. University courses are sometimes criticised for not containing "Costing" as a separate subject. Costing is important, but elementary costing introduces no new principles, and it does not seem worthy of direct introduction into undergraduate courses. In my view, it can be best learned by application, but there may be a case for post-graduate instruction by those who have years of experience of the errors which sometimes result. Are pounds or dollars the only things on which we base the cost?

Anyone equipped with a sound fundamental knowledge should grasp anything new to him, provided that it is clearly written, and that he has the time to read and apply it. A first essential in the undergraduate course, then, is to ensure that the basic training is such that the graduate, from his own reading, can appreciate developments not specifically covered by his undergraduate course or which have occurred since his time at the university. This basic training needs to be continually reviewed.

The art of engineering is, in part, the art of making the right approximations, or hypothesis, and of realising the errors which may arise. The approximations will change with the type of design being considered, so that approximations will have to be dealt with clearly in our undergraduate courses. In illustration of past obscurity, the comments of most text-books, that the flange shear stress is negligible, comes to mind. Now if this concept is extended to a tubular bridge, say, Fairbairn's and Stephenson's Britannia Bridge over the Menai Straits, it might be concluded that there is no shear in the upper flange. The argument is equally applicable to the strength decks of ships. If this is so, how can distributed booms carry loads? What mechanism is there for getting load into them? Going back through the argument, you find that the text-books have been considering just vertical shear, and the possibility that there might be a horizontal shear is hardly mentioned. Without it there is no mechanism to use distributed flanges. This illustration I have introduced to show the need for a continual review of accepted basic instruction. Even now, I have not mentioned "shear lag."

(To be continued.)

RESEARCH FELLOWSHIP IN AERONAUTICS.—The English Electric Company, Limited, Queen's House, Kingsway, London, W.C.2, have established a new research fellowship, valued at 500*l.* a year, at the University of Glasgow, for the study of advanced problems in aeronautical engineering. Holders of the fellowship will carry out investigations on aircraft vibration, stability, and control, under the supervision of Professor W. J. Duncan, F.R.S., Mechan Professor of Aeronautics and Fluid Mechanics. The Fellowship will be awarded by a board constituted by the University of Glasgow; the first Fellow will be selected early in 1952.

RUTHERFORD MEMORIAL.—In a letter to *The Times*, the President of the Royal Society, Dr. E. D. Adrian, states that "steps are being taken which will enable the first Rutherford memorial scholar to be appointed, to take up his scientific work in some part of the Commonwealth on October 1, 1952, and that the Council of the Royal Society has appointed Sir John Cockcroft as the first Rutherford memorial lecturer; it is proposed that he should visit New Zealand in the autumn of 1952." Contributions to the fund are still being received; in the United Kingdom about 70,000*l.* has already been given or promised, and in the Commonwealth there is likewise a successful response to the appeal.

LABOUR NOTES.

NEGOTIATIONS on proposed wage increases for engineering employees in railway workshops, which took place in London on Monday last at a meeting of the Railway Shopmen's National Council, were unsuccessful. The meeting was eventually adjourned until yesterday, to enable both sides to consider the position privately. The Council comprises representatives of the Railway Executive, the National Union of Railwaymen and the Confederation of Shipbuilding and Engineering Unions, and the outcome of yesterday's meeting was not available at the time of going to press, but it is probable that the claim will be referred to arbitration in the event of an agreement not being reached before the Christmas holidays.

The demands put forward by the employees' side of the Council some weeks ago were for a "substantial increase" in the wages of the railway shopmen. It is understood that the Railway Executive made an offer which would have increased the men's wages by approximately 8 per cent. Such an advance would have been in line with the concessions in pay recently granted to the other employees in the railway service. The men's unions, on the other hand, desire that the increase granted to the shopmen shall amount to at least 11*s.* a week, in accordance with the advance agreed to at the end of last month for employees in the engineering industry. The Confederation and the N.U.R. also seek to restore the craft differentials which obtained in the railway workshops prior to the award of the all-round wage increase to railway shopmen some months ago. It is estimated that there are between 120 and 130 thousand railway employees who will be affected by the present wage claim.

Among a number of wage claims which have been successfully negotiated during the past week was one on behalf of clerical employees in the gas industry. Under the terms of an agreement reached between the two sides of the National Joint Council for Gas Staffs, and announced on Monday last, adult male employees will receive advances in their pay ranging from 5*l.* to 25*l.* a year. Increases granted to women clerical staffs will vary from 4*l.* to 20*l.* a year, and there will be proportionate improvements in the wages of boy and girl employees. Some 20,000 employees in all are expected to benefit from these concessions, which will come into operation on January 1.

Wage improvements for ships' radio officers were agreed to at a recent meeting of the National Maritime Board. According to this settlement, sea-going radio officers included on the Board's panel will receive increases ranging from 2*l.* to 3*l.* 15*s.* a month. Special allowances for foreign service, starting at 5 per cent. of the basic rates, have also been conceded. These allowances will amount to 10 per cent. in the case of some radio officers required to serve in ships permanently engaged abroad. Increases under this agreement will date from January 28.

Industrial personnel employed in naval dockyards are to receive an increase in wages of 11*s.* a week, according to the terms of an agreement reached at a meeting of the Shipbuilding Trades Joint Council and announced on December 11. Their wages will thus be brought into line with those obtaining in the engineering industry generally, in which employees were recently granted increases averaging 11*s.* a week each.

The wage offer made recently by the National Coal Board to members of the National Union of Mineworkers has been accepted by 73 branches of the union, according to a statement made by Mr. Abe Moffat, the President of the Scottish area of the N.U.M., at a meeting of the area's executive committee in Edinburgh on Monday last. Mr. Moffat also informed the committee that, up to that date, no branch of the union had rejected the offer. The Board's offer provides for a minimum wage of 7*l.* 0*s.* 6*d.* a week for underground employees. The committee adopted a resolution sponsored by the union's Roslin branch. This condemned the statement made by the Trades Union Congress that it would "work amicably" with the present Government.

Miners' representatives from Yorkshire and other areas in Britain may visit Italy in the near future to see how prospective recruits for British collieries are employed in their own country. Suggestions that arrangements to this end should be made at an early date were put forward by the leaders of the Italian Free Trade Union Confederation during discussions with officials of the Yorkshire area of the National Union of Mineworkers on how the introduction of Italian labourers to British pits might be achieved most successfully. A team of six Italian trade unionists, headed by Mr. Enricco Parri, vice-secretary of the Confederation, has recently been studying conditions at collieries in the Yorkshire area. The team also visited the training centre for Italian entrants to the British mining industry, at Maltby, Yorkshire.

Recent suggestions that the objections to receiving Italian mining employees might be overcome by handing over entire pits to Italians were not favourably received by Mr. Parri, who contended that his countrymen should not be isolated, but encouraged to enter into English life in the area in which they were employed. As to the somewhat disappointing reception of the Italians by Yorkshire miners, Mr. Parri stated that he understood the objections of men who were proud of their craft and who were concerned that strangers entering a dangerous industry might be a hindrance to the practical task of getting coal.

There was little change in the size of the total working population of Great Britain during October, when a marginal increase in the number of men was offset by a slightly larger decline in the number of women. At the end of the month, the working population totalled 23,479,000 persons, of whom 16,034,000 were men and boys, and 7,445,000 were women and girls. These figures represent the total number of persons, aged 15 and over, who work for payment or gain, or who register themselves as available for such work. The total comprises persons serving in the Armed Forces, men and women on release leave seeking employment, registered unemployed, and all persons—employers and persons engaged on their own account as well as employees—in civil employment. Private indoor domestic servants and gainfully-occupied men and women over pensionable age are also included. In these statistics, part-time workpeople are counted as full units.

Of the total at the end of October, 22,350,000 persons, comprising 15,044,000 men and boys and 7,306,000 women and girls, were engaged in civil employment (industry, commerce and services of all kinds), a decrease of 20,000 men and 29,000 women, including juveniles in each case. The size of the Armed Forces, according to statistics issued by the Ministry of Labour and National Service at the end of last week, rose by 4,000 during the month, all of whom were men, to an end-of-the-month total of 844,000. This total comprised 821,000 men and 23,000 women. There were 9,000 ex-Service men and women on release leave seeking employment at the end of October, compared with 8,000 at the end of the preceding month, and 92,000 at the end of June, 1948. Persons registered with the Ministry as unemployed rose in number from 235,000 at the end of September last to 276,000 at the end of October, an increase of 41,000. There were, however, 328,000 persons registered as unemployed at the end of December, 1950.

There was a decrease of 34,000 during October in the number of persons employed in the basic industries, which comprise mining, quarrying, agriculture, fishing, gas, electricity, water, transport and communications, thereby reducing the total number engaged in this sphere of industrial activity from 4,191,000 persons at the end of September to 4,157,000 persons at the end of October. There was no variation in the numbers of workpeople employed in the manufacturing industries, the total for both September and October being 8,746,000. This section comprises operatives engaged in the chemical and allied trades, the food, drink and tobacco trades, the textile industry, the clothing industry, and the metal, engineering and vehicle-building group of industries, as well as those employed in other types of manufacture. There was a decline of 10,000 in the total for the textile industry during October, and one of 19,000 for the clothing industry, but the total for the metal, engineering and vehicle-building group of industries advanced by 21,000 during the same period, to an end-of-the-month total of 4,171,000.

Slightly more than 1,448,000 persons were employed in the building and contracting industries at the end of October last, and some 2,653,000 in the distributive trades, about the same numbers as at the close of the preceding month. There were, in all, 3,935,000 men, women and juveniles in the professional, financial and miscellaneous services at the end of October, about 11,000 fewer than at the close of September. Public administration provided work at the end of October for some 1,411,000 people; 641,000 in Government Departments and agencies, and 770,000 in the various sections of local-government service. The total for public administration does not include the large number of persons employed in the several nationalised industries, as these workpeople are included elsewhere, under their respective headings. The Ministry of Labour records that unemployment on November 12 last represented 1·4 per cent. of the estimated total number of employees on that date, compared with 1·5 per cent. at mid-November, 1950.

SOME FUEL AND POWER PROJECTS.*

By H. ROXBEE COX, Ph.D., B.Sc. (Eng.)

(*Continued from page* 728.)

IN all our work on fresh means for using coal, the aim is to develop machines which do not need to discriminate in the coals they use. This means that our coal-consuming gas turbines must use high-ash fuels, which immediately poses the question of how to deal with the residual ash so that it does no harm to the turbine. One way is to use dry burning and to clean the whole gas throughput with more or less conventional cleaners. This is the method adopted in the Parsons engine. Here the problem is to clean down to a size of dust particle which will not abrade the turbine blades—a double problem because, in addition to finding how best to clean to a given size, there is the problem of what size to clean to. Opinion is still divided on the critical magnitude, varying from 5 to 20 microns.

Another method is to use a slagging combustion chamber (Fig. 8) and to withdraw most of the ash as molten slag. This method of getting rid of the ash is that adopted in the 2,000-kW English Electric engine just described and has been the subject of recent experiment by John Brown and Company, Limited. The gas may require further cleaning, depending upon the size of particle which is carried through, and a conclusion on what is the critical size. This additional cleaning could be done before or after the gas is mixed with the diluent air.

So long as we stick to internal-combustion gas turbines, there would seem to be only one other practical possibility, a method which is an important advantage of the kind of engine to be described in this section. By arranging the combustion in two stages, with the first stage producing combustible gas and the second stage its combustion, cleaning may be confined to the first or gasification stage. In the particular engine on which work is in hand, this means that only about 10 per cent. of the throughput has to be cleaned, compared with about 40 per cent. with the slagging chamber and 100 per cent. with dry combustion. This leads to the hope that two-stage combustion may permit the use of coals which are inconveniently dirty for single-stage combustion open-cycle engines.

The cycle diagram for the engine is in Fig. 10. The main turbine engine, of 2,000-kW capacity, is being built by the Metropolitan-Vickers Electrical Company, Limited, and is due to be ready in May, 1952. The supercharging turbo-compressor is also being provided by this company and it will have considerable interest in its own right, as it has an inward flow (radial) turbine with controllable-incidence entry guide vanes. The design of the gas producer is the joint work of the Incandescent Heat Company, of Smethwick, and Joseph Lucas (Gas Turbine Equipment), Limited, of Burnley. The detail design and construction of the producer is by the Incandescent Heat Company. The particulars of the full-scale plant, which it is hoped will operate in 1952, are shown in Fig. 10, on page 794.

The working pressure of the gas producer will be about 6 atmospheres and no producer heretofore made in Great Britain has had a superpressure of more than a few inches of water. If successful, the pressurised gas producer may well have applications far beyond the plant for which it has been designed. As it is so novel a venture, that we have decided not to make the producer without trying a pilot-scale producer first is not surprising. This pilot-scale plant, which has an air throughput of 1 lb. per second, is shown in Fig. 11 on the test rig at the Burnley works of Joseph Lucas, where it has been running since September, 1951.

The gasification chamber, which works at 6 atmospheres, is of the cyclone-vortex type and is designed to run under slagging conditions. The main air supply, which is preheated in a paraffin heater designed for the test-rig work, passes through the tripod pipe arrangement and enters the gasification chamber tangentially. The finely divided coal is pumped in on the centreline of the chamber. The lower vessel in Fig. 11 is a chamber for slag collection and gas cleaning, the gas exhaust passing away down the pipe on the right.

I have indicated three methods of preventing the ash in the products of coal combustion damaging the turbine of the open-cycle gas turbine. The remaining and most obvious method is to prevent the products of combustion passing through the turbine. This necessarily means departing from the internal-combustion cycles. The simple open cycle with external combustion is shown in Fig. 12. The combustion air in the furnace is preheated by the turbine exhaust. This would appear to be another cycle capable of using high-ash fuels, and with the additional advantage of simplicity. It seems, in consequence, likely to be suitable for a locomotive which, like many foreign engines, has to use fuel of poor quality. An ability to do the same in Great Britain would be a genuine easement in the problem of coal supply, providing that a real reduction in consumption were achieved and overall economy were maintained.

The conventional piston-engine steam locomotive is long-lived and low in capital cost, but its average thermal efficiency in operation is only about 5 per cent. Consequently, coal costs figure so highly in a year's intensive duty that a 50 per cent. fuel saving would allow about four or five times the present annual expenditure on capital charges. In other words, a coal-burning locomotive giving twice the current average fuel efficiency could be allowed to cost about four or five times as much as the present type.

It seems that such a capital cost figure is likely to be achieved with an open-cycle external-combustion coal-burning gas turbine with direct drive, and the Ministry

Fig. 8. CYCLONE SLAGGING COMBUSTION CHAMBER FOR 2,000 KW ENGLISH ELECTRIC COAL-BURNING GAS-TURBINE SET.

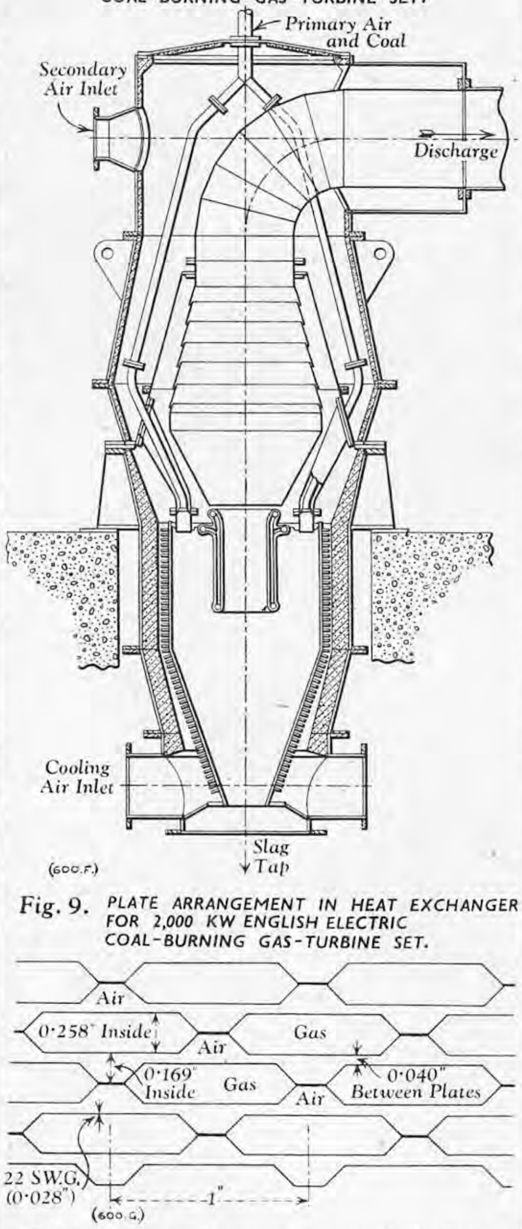
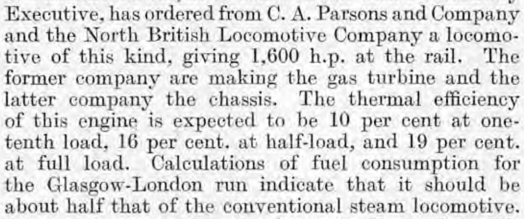


Fig. 9. PLATE ARRANGEMENT IN HEAT EXCHANGER FOR 2,000 KW ENGLISH ELECTRIC COAL-BURNING GAS-TURBINE SET.



of Fuel and Power, after consultation with the Railway Executive, has ordered from C. A. Parsons and Company and the North British Locomotive Company a locomotive of this kind, giving 1,600 h.p. at the rail. The former company are making the gas turbine and the latter company the chassis. The thermal efficiency of this engine is expected to be 10 per cent at one-tenth load, 16 per cent. at half-load, and 19 per cent. at full load. Calculations of fuel consumption for the Glasgow-London run indicate that it should be about half that of the conventional steam locomotive. A general arrangement is shown in Figs. 13 to 16, on page 795.

The leading particulars are: power at turbine shaft, 1,800 h.p.; maximum rail horse-power, 1,600; wheel base, C_3-C_3 (0-6-6-0); gauge, 4 ft. $8\frac{1}{2}$ in.; length over buffer beams, 64 ft. 6 in.; length overall, 68 ft. 6 in.; maximum width, 8 ft. 8 in.; maximum height, 13 ft.; wheel diameter, 4 ft. 6 in.; total weight, 117 tons; maximum axle load, $19\frac{1}{2}$ tons; normal maximum speed, 75 m.p.h.; starting tractive effort, 30,000 lb.; maximum tractive effort in low-speed range, 45,000 lb.; maximum speed in low-speed range, 50 m.p.h.; fuel capacity, 6 tons (say, 500 miles); maximum turbine temperature, 1,300 deg. F.; maximum heater temperature, 1,560 deg. F.; maximum speed of power turbine, 8,000 r.p.m.

Exhaust air from the work turbine is partly used for combustion and partly to reduce the temperature of the burnt gases before they enter the air heater. These gases give heat through the walls of the tubular air heater to the compressed air, which is the working medium, on its way to the turbine. The compressor is driven by the high-pressure turbine and the low-pressure turbine provides the power output. The torque characteristics of the power turbine resemble those of the conventional steam locomotive, permitting direct drive. A two-stage gearbox gives a choice of gears for passenger and freight work. Train heating is provided by a steam boiler, heated by the exhaust gases from the air heater on their way to atmosphere.

In the closed-cycle gas turbine, as in the externally-fired open-cycle engine just described, the products of combustion do not pass through the main turbines. In examples of the closed-cycle engine so far built, this clear advantage is neutralised to some extent by the fact that the combustion products necessarily pass through the turbine used for supercharging the air heater. With air heaters running at atmospheric pressure, however, any ash in the products of combustion cannot attack the rotating machinery and its damaging effects are confined to the air-heater tubing. It is with this version of the closed-cycle engine in mind that the Ministry of Fuel and Power have ordered from John Brown and Company an atmospheric coal-burning air heater to be run with either the 500-h.p. John Brown experimental closed-cycle gas turbine or with a 1,000-h.p. engine which they have in hand. The cycle arrangement is shown in Fig. 17, on page 795. The air heater (Figs. 18 and 19, on page 795) has a straight-through combustion chamber. This refractory-lined chamber has been run as both a dry-burning and a slagging chamber, and has given very encouraging results. The experience of slagging which has been obtained will be of value in the development of a cyclone slagging chamber which the Ministry has ordered as an alternative to the straight-through chamber.

In all the gas-turbine plants described, coal has to be injected into the combustion chamber and, except in the locomotive engine, against a pressure of several atmospheres. Though, on test rigs, lock hoppers can be used to do this, the only practically satisfactory solution is a good coal pump. Two coal pumps have been developed to an advanced stage by the Incandescent Heat Company. One, which has been made for the gas-producer test rig (Fig. 11) is of the rotating-disc type, and the other is of the reciprocating ram type.

In the rotating-disc pump, coal is fed under gravity into small cylindrical pockets situated on a pitch-circle diameter of approximately three-quarters of the overall diameter of the disc, which is mounted horizontally. The bottoms of the pockets are sealed with small spring-loaded valves. Rotation of the disc causes the pockets, filled with coal, to pass under a seal into the pressure-air discharge line, the air flow being such as to unseal the pockets and scavenge them of their coal. Before the empty pockets arrive at the charging chute for re-filling with coal they pass under a small suction port which discharges their pressure-air content.

In the reciprocating type of pump, a charge of air-coal mixture is drawn under a small depression through a rubber ball valve into the cylinder on the outward stroke of the ram, and then this mixture is compressed and finally discharged through another ball valve into the high-pressure line during the inward stroke. Successful preliminary running has been done on both types of pump against pressures of from 3 to 6 atmospheres with pulverised coal.

So far, I have been describing ways of using coal directly as a fuel. Two familiar derivatives from coal are also the subjects of interesting experiments. One of these derivatives is that unpleasant concomitant of coal mining, namely, firedamp. The other is coal gas.

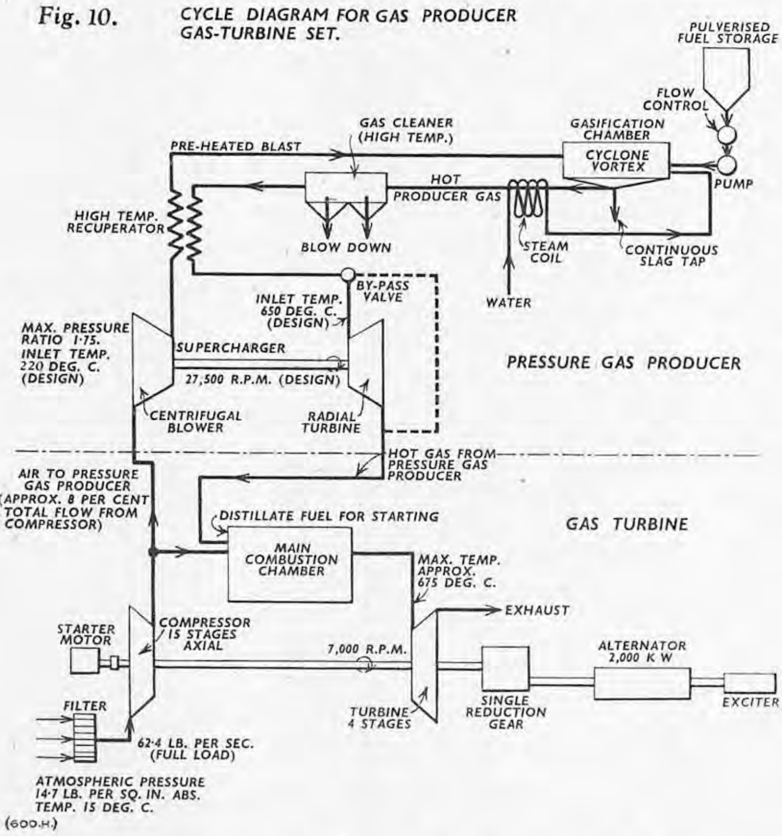
It was pointed out by C. H. Secord in 1948 that the methane or "firedamp" occurring in small percentages in the ventilating upcasts from mines was sufficient, if it could be converted into useful energy, to run all the colliery machinery in Britain. The methane usually occurs in amounts less than 1 per cent., though in a few pits figures above 1 per cent. are recorded. One way of using some of this available energy is to use the upcast gas, instead of normal air, under steam boilers; but this method would only convert about 15 per cent. of the methane in the upcast.

Secord proposed that the upcast methane-air mixture should be used directly in a gas turbine and so permit pithead generation of electrical power from a free fuel. This proposal clearly depended upon finding a practical means of burning such an exceptionally weak mixture as 1 per cent. or less of methane in air. R. G. Voysey proposed for this purpose a "temperature booster"

* The 38th Thomas Hawksley Lecture, delivered to the Institution of Mechanical Engineers on Friday, November 16, 1951. Abridged.

FUEL AND POWER PROJECTS.

Fig. 10. CYCLE DIAGRAM FOR GAS PRODUCER GAS-TURBINE SET.



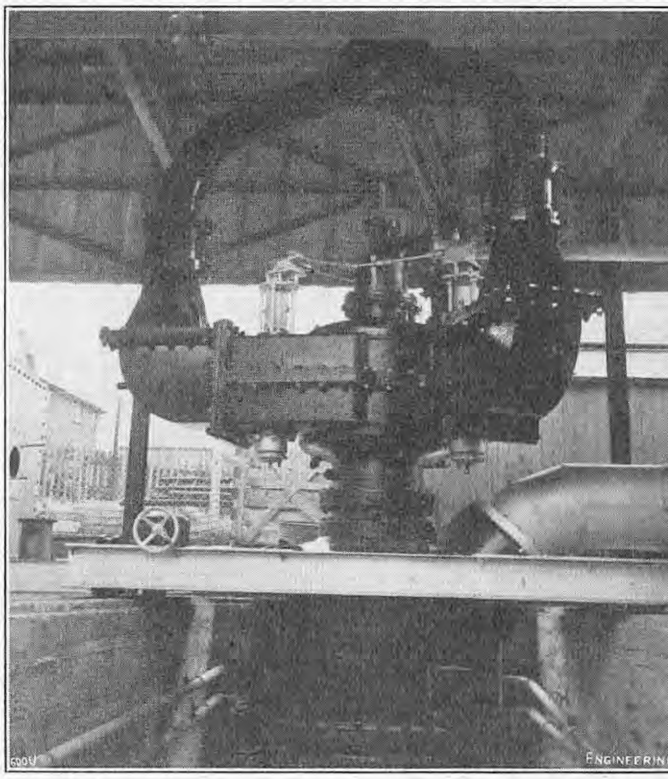


FIG. 11. PILOT GAS PRODUCER FOR GAS TURBINE.

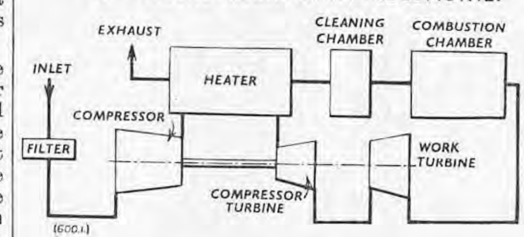
which is, in effect, a regenerative heat exchanger combined with a combustion chamber. This device depended upon the assumption that, if the weak mixture were sufficiently preheated, it would oxidise at a reasonable temperature; the heat of combustion was proposed as the means of preheating.

It was clearly essential at the outset to determine the conditions for combustion of weak methane-air mixtures, and this work was undertaken by Sir Alfred Egerton and his staff at the Imperial College. The experiments which they did are of absorbing interest and have a scientific importance beyond the immediate reasons for doing them. In Fig. 20, on page 796, are reproduced the curves which permitted practical design work on a firedamp-burning gas turbine to be begun. It can be seen that, if preheating to about 1,000 deg. C. (1,832 deg. F.) is arranged, then combustion, or more accurately, nearly complete oxidation, occurs. A simple firedamp-burning gas turbine with cycle temperatures corresponding to this figure was the original conception.

It was soon apparent, however, that, excepting for the abnormal case of very gassy pits, this cycle led to a derated gas turbine which, on economic grounds, was undesirable, and the original conception was modified to the idea of a gas turbine of optimum thermodynamic design, burning the upcast gas and an auxiliary fuel. This was a far more useful and interesting proposal than the original one, for at all collieries there is a supply of coal fines which are generally not worth transporting, so that the target became a gas-turbine plant based on the two free fuels which a pit can provide—upcast gas and low-grade coal. We visualise, therefore, an ultimate fusion of the work on weak methane-air mixtures and on the coal-burning gas turbine. In the meantime, the obvious practical course is to develop a gas turbine which burns the upcast gas together with an auxiliary fuel more tractable than coal fines. This is our immediate target. The most attractive auxiliary fuel, and, indeed, the most natural one until coal itself is used, is coke-oven gas, though for experimental purposes we shall, as convenient, use any other available auxiliary—oil, town's gas, or producer gas—in connection with which the possibility of combining the producer-gas gas-turbine idea with the firedamp gas-turbine idea is kept in mind.

A firedamp gas turbine has been ordered by the Ministry from the English Electric Company, Limited. Basically, the engine is the same as the coal-burning engine which this company are making, and perhaps, in consequence, the most practical engine using firedamp and auxiliary coal may be the descendant of these forebears. The first engine, however, will employ as the auxiliary fuel, to begin with, a clean fuel such as a distillate oil or gas and the cycle, illustrated in Fig. 21, is designed so that part of the firedamp is burnt in a

Fig. 12. EXTERNALLY COAL-FIRED OPEN-CYCLE GAS-TURBINE FOR PARSONS NORTH BRITISH LOCOMOTIVE.



temperature booster and the rest burnt as the combustion "air" for the auxiliary fuel. This project is going ahead with the full collaboration of the National Coal Board. The Ministry is purchasing the plant and the National Coal Board is paying for its installation at a colliery, where it should begin to run towards the end of 1951. There are two novelties in this kind of plant. One is the original notion of burning weak mixtures. The other is the physical means of doing it, namely, the temperature booster. A pilot temperature-booster to handle 1 lb. of air per second at a pressure of 5 atmospheres has been constructed. This is essentially a ceramic regenerator with pneumatically-operated mushroom-type valves at the low-temperature ends and with a bridging reaction chamber across the high-temperature ends. The ceramic matrix in each leg is composed of layers of thin high-alumina slats, packed on edge, with narrow gas-passages. In the next layer, the slats lie at 60 deg. to those in the first layer. These two arrangements alternate. The air containing the firedamp is admitted through the appropriate valve to the bottom of a leg and proceeds upwards, receiving heat from the ceramic matrix until its temperature is raised to the point at which oxidation of the methane proceeds rapidly. The heat exchanger is so designed that this temperature is reached just before the top of the matrix. The oxidation is completed in the reaction chamber, and the air and gas products are raised in temperature a further amount depending on the original methane content and the proportion consumed. These hot gases then pass down through the other leg, giving up heat to the ceramic matrix before passing out through the gas valve diagonally opposite to that used for admission. After these conditions have continued for a time, one matrix (on the "air" side) will be cooled and the other matrix (on the "gas" side) heated. Before this cooling and heating has proceeded too far, the flow direction is reversed by opening the closed valves and closing the open valves. After the appropriate interval, the flow is reversed again, and so on, so that the temperature booster operates as a regenerator with a temperature difference produced by the reaction to "drive" the heat exchanger.

When a fuel has been produced or generated with maximum efficiency, and when it has been turned into heat energy with maximum efficiency, there normally remains only the problem of using the heat with the maximum efficiency. There is an additional possibility, however, which is sometimes worth considering—that of using the energy to make available additional heat from another source. There is a vast quantity of natural heat in the Earth, its air and its waters, mostly at too low a temperature to be directly used. Lord Kelvin pointed out that by means of a "heat pump" this low-grade heat could be transformed and delivered as high-grade heat. The work necessary to do this can be supplied by an engine running on coal, peat, gas, or electricity; the choice depends on the circumstances of the case, though coal and peat are not likely to be frequent choices for the purpose. The popular choice has been electricity, and the sizeable heat pumps in Great Britain are all electrically driven.

The possibility of exploiting a free source of energy is always attractive. It is, however, sometimes expensive to build the means of turning free energy into a more acceptable and usable form, and the initial attraction of getting something for nothing is often clouded by the realism of an economic assessment. Tidal power is balanced on an economic knife edge. Hydro-electricity, so obviously right against one background, can be wrong against another. The heat pump, though it can always deliver more heat than is in the fuel it consumes, is not always the best answer to a heating problem. In some circumstances, however, it appears to be very superior indeed, and we felt that we should try to obtain some genuine full-scale economic data to provide a sound basis for design. The particular opportunity offered was one for which the basic fuel was gas.

At the time when we were looking for an opportunity to test a full-scale heat pump, we learnt that the Royal Festival Hall was to be heated by gas-fired hot-water boilers. One of the reasons for this choice was that it avoided the inconvenience, on a site where the preservation of amenity was clearly important, of solid fuel and ash handling. Such considerations, so obvious in this instance, are, I feel, too frequently overlooked: even the costs of cleaning large buildings inside and out are not taken into account in weighing up the pros and cons of different possible heating schemes. Had such considerations been completely ignored, and the problem been one of heating alone, our preliminary assessments suggested that a gas-driven or electrically-driven heat pump would be more costly than simple coke-fired boilers. The gas-operated heat pump, however, looked like being rather more economical than the gas boilers, particularly if a high load-factor could be relied on, and if as much as possible of the waste heat from the gas-engine prime movers

FUEL AND POWER PROJECTS.

Fig. 13. PROPOSED PARSONS NORTH BRITISH COAL-BURNING GAS-TURBINE LOCOMOTIVE.

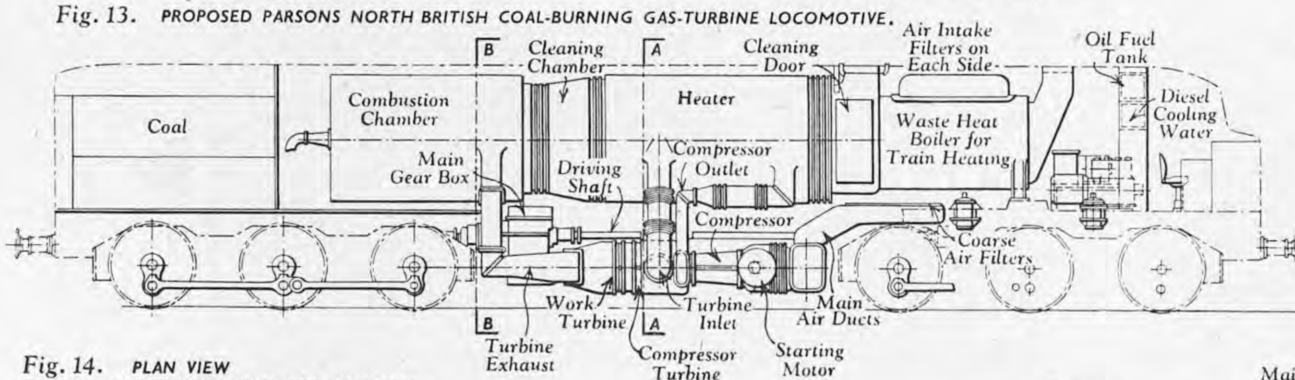


Fig. 14. PLAN VIEW (HEATER AND MIXING CHAMBER OMITTED).

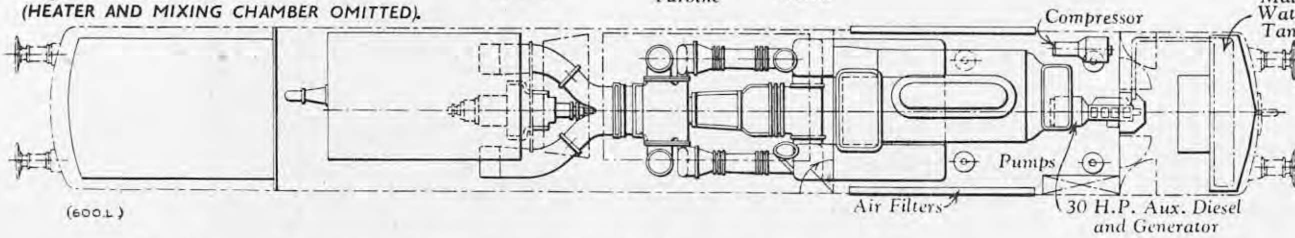


Fig. 15. SECTION A-A VIEW ON TURBINE INLET.

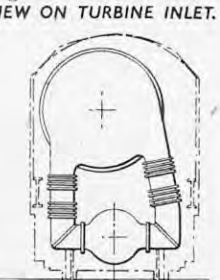


Fig. 16. SECTION B-B VIEW ON COMBUSTION CHAMBER INLET.

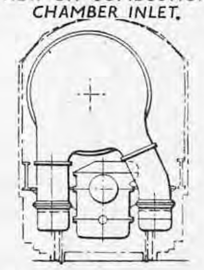


Fig. 17. JOHN BROWN COAL-FIRED CLOSED-CYCLE GAS-TURBINE PLANT WITH ATMOSPHERIC AIR HEATER.

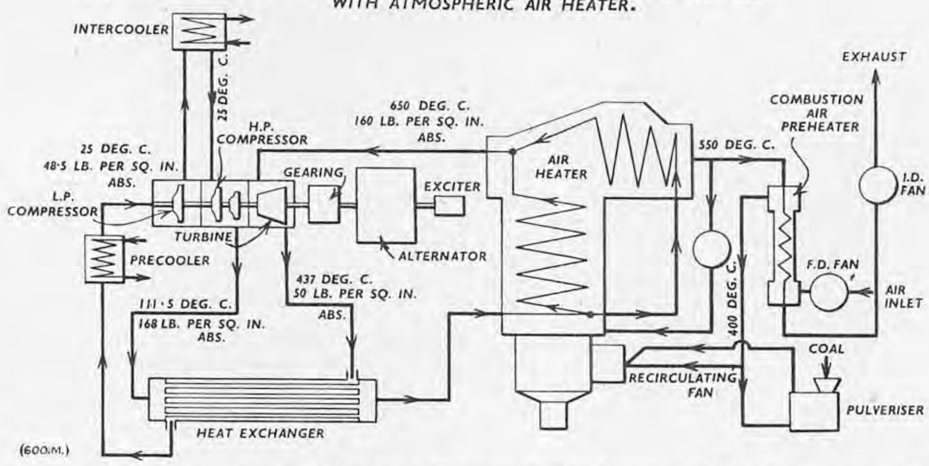


Fig. 18. ARRANGEMENT OF COAL-FIRED AIR HEATER WITH ATMOSPHERIC COMBUSTION.

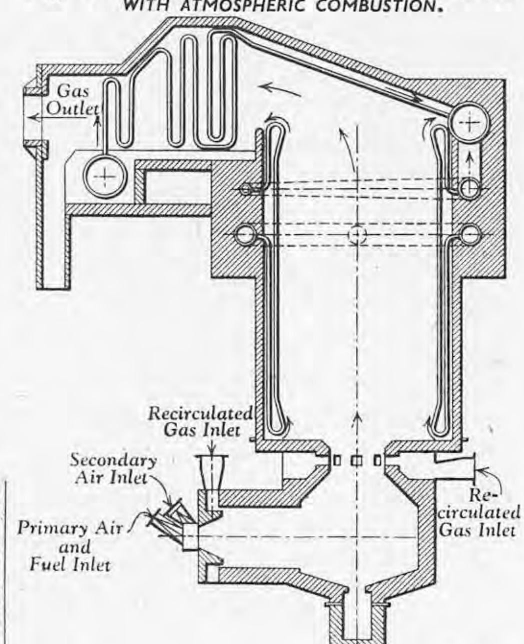
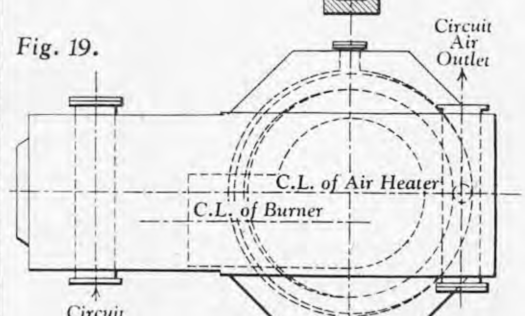


Fig. 19.



was recouped. If, too, the apparatus were used for providing summer cooling and so could legitimately be compared in cost with the equivalent boilers and a refrigerating plant, the economic picture for the heat pump looked distinctly attractive. An arrangement was made with the London County Council that the Ministry would build a heat pump which initially would be tried as an alternative to the heating boilers of the main hall. If it proved successful, the London County Council would be given the opportunity of purchasing the plant.

The engines were originally supercharged Rolls-Royce Merlin 140 aircraft engines, and they were converted to run unsupercharged on gas, with a maximum rating for the heat-pump work of 350 h.p. Parts of the superchargers were modified to form the basis of the two centrifugal compressors. The river water is supplied through a remotely controlled variable-speed electrically-driven centrifugal pump, fixed to a platform in the middle of the River Thames. The concert-hall water is tapped from the main return flow to the gas boilers installed by the London County Council and is circulated by a centrifugal pump, belt-driven from the first-stage compressor engine. The evaporator is of the shell and tube type.

Before delivery to the concert hall, some of the water is by-passed for engine and oil cooling and this part of the "waste heat" is thereby recovered. Exhaust heat is recovered by passing the whole flow to the concert hall through an exhaust-heated boiler. At maximum output, when each engine is developing 350 h.p., the total consumption is 12,000 cub. ft. of town's gas per hour. The flow of refrigerant is then about 25 lb. per second. The river-water flow is about 1,800 gallons per minute and the flow of the concert-hall water about 500 gallons per minute, the maximum water output temperature is 165 deg. F., and the maximum heat output is 90 therms per hour.* The overall efficiency, based on the calorific value of the gas burned, is 150 per cent.

The heat pump was completed and ready to run on the day before the Festival opened. It was not required immediately, however, and the first run was on May 10, 1951. Subsequently, a number of short test runs were made, using the plant to supply heat at a comparatively low rate. After stripping the plant for inspection, it was ready for duty again at the beginning of July and began to run almost daily, supplying chilled water to the air washers in the concert hall. Designed with the heating requirement as the first priority, the plant is oversize for cooling, but during the early stages of a run, when the plant is cooling the water to the correct temperature, it can operate near to the design load of one engine. A typical set of figures for such a condition is: rate of flow of water to concert hall, 290 gallons per minute; temperature of water from hall, 53 deg. F.; temperature of water to hall, 41·2 deg. F.; rate of flow of river water (approximately), 500 gal. per minute; temperature of river water into plant, 75·3 deg. F.; temperature of river water out of plant, 85·0 deg. F.; gas consumption, 4,800 cub. ft. per hour. This gives a heat extraction rate of 20·6 therms per hour for a gas consumption of 24·7 therms per hour. Allowing 30 per cent. thermal efficiency for the engines, this gives a refrigerating performance of 2·78 to 1.

Of the several ways of obtaining gas from coal there are two which have long been the subject of discussion, speculation, and preliminary experiment, namely, "underground" gasification and "total" gasification. Neither of these terms defines a single process; there are many ways of doing each. Each, however, defines a single broad idea, an idea which needs most careful examination because, if it were successfully translated into practice, it could have tremendous consequences. Fresh consideration has been given, therefore, both to underground gasification and total gasification.

The idea of obtaining energy from coal without first mining it is not new, but practical progress has been confined to the past 20 years. Since 1931 there has been a great deal of work done in Russia, but it is difficult to assess the scale of operation and the progress made. In western countries, there has been considerable experimental activity since the 1939-45 war. Interesting data have been obtained in Belgium, the United States, Italy, and French Morocco as well as in Great Britain.

The energy obtained from underground gasification is the result of a producer-gas reaction accompanied by the distillation of volatiles and, usually, some water-gas reaction. The product is generally a combustible gas of low calorific value but high temperature. If it can be produced economically, we aim to use it, on the site, as the fuel for electricity-generating machinery. The other possibilities of distributing it as town's gas or using it as a synthesis gas for liquid-fuel manufacture are not yet being seriously considered here: their practicability depends upon greatly improving the quality of the gas produced at an economic cost.

The work done here has been different so far in two important ways from the work in the other western countries. In the first place, our idea has been to try to make use of coal which would not be mined because of its poor quality or for some other reason which made bringing it to the surface uneconomic. Britain has hundreds, possibly thousands, of millions

* This plant was described and illustrated in ENGINEERING, vol. 171, page 741 (June 22, 1951).

FUEL AND POWER PROJECTS.

Fig. 20.
OXIDATION OF WEAK METHANE-AIR MIXTURES.

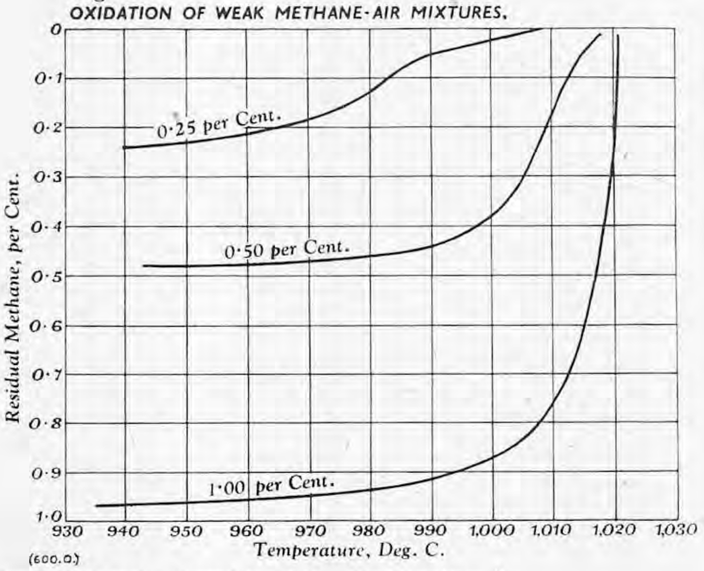
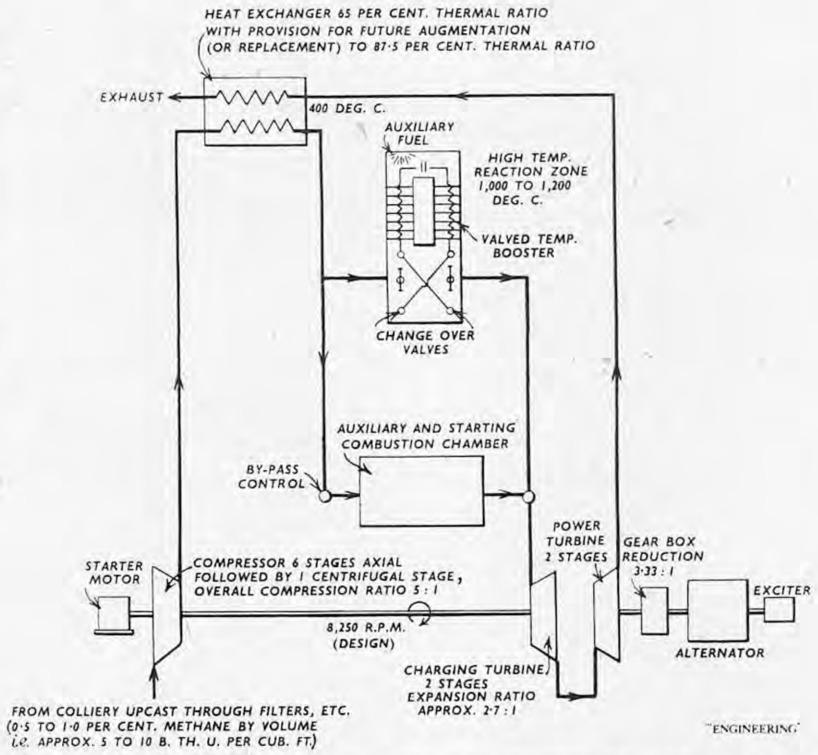


Fig. 21. CYCLE DIAGRAM OF 2,000 KW ENGLISH ELECTRIC FIREDAMP BURNING GAS-TURBINE SET.



of tons of such coal. Secondly, in these other countries, the systems have been made by mining, and the objective has generally been the gasification of that portion of a sloping seam lying above a horizontally-mined gallery. With a considerable effort being applied elsewhere to this line of attack, we have devoted attention here to methods which do not involve mining, methods of creating underground systems which can be worked from the surface. Whether this approach will prove to be more or less economical than the alternative being examined in the other countries will not be known for some time to come. Close liaison is being kept with the work in the United States, Belgium, and France, and it may be necessary later to try under British conditions the methods being investigated in those countries, before a conclusion can be reached on the economics of underground gasification of British coals.

(*To be continued.*)

RESEARCH ON CAST IRON.

THE factors influencing the fluidity of cast iron have been studied for some time past in the laboratories of the British Cast Iron Research Association, at Alvechurch, Birmingham, and it is stated in the Association's annual report for the year ended June 30, 1951, that good progress has been made in a research based on the use of a spiral test-piece. The work indicates that low-phosphorus high-carbon irons can be made as fluid as the high-phosphorus irons. The investigation, it is added, has now been terminated and a comprehensive final report on the subject is to be published shortly. During the year a good deal of work has also been conducted on the estimation and the influence of the gaseous elements in cast iron. The vacuum-fusion apparatus, employing high-frequency heating, has been improved and techniques of sampling studied. The gas adsorbed on the specimen's surface and the influence of various metallurgical treatments on the gas contents of cast iron have received attention. The oxygen content of many cast irons has been found to be very low. It is emphasised that this particular field of investigation is extremely difficult and that progress is expected to be slow.

In connection with malleable cast iron, two investigations have been proceeding in the laboratories. One is concerned with the effect of graphitisation on the rate and extent of decarburisation, which is pertinent to the white-heart process, and the other deals with the mechanism of the formation of the carbide film that can occur at the edge of black-heart malleable castings. In addition, many field tests have been carried out on the use of higher manganese : sulphur ratios than are normal in the white-heart malleable-iron industry. Among other work in progress, a long-term investigation on shrinkage and porosity defects in cast iron has been put in hand, and comprehensive examinations of the meaning of the impact test applied to cast iron, and of the fatigue properties of nodular and other cast irons, are being continued. A Charpy impact machine is to be used to test V-notched and "key-hole" notched specimens of geometrical similarity and varying dimensions, and a prototype fatigue testing machine has been completed. Some work has also been carried out on the electrical resistivity of cast iron and a brief report on this is to be published shortly.

IDENTIFICATION COLOURS FOR ALUMINIUM ALLOYS.

THE well-known Technical Association of Light Alloy Refiners, Alar, Limited, 3, Albemarle-street, London, W.1, which distribute, at intervals, data sheets, reprints of papers and other publications relating to the production and properties of aluminium casting alloys, have now prepared a new data sheet entitled "Colour Scheme for the Identification of Aluminium Casting Alloys." They state that some founders prefer their ingots to be identified by colour instead of the more common stamped specification number. Unfortunately, however, no single system of colours has been adopted,

Alloy Type.	Colour.	Alloy Specn. B.S. No. 1490.	Old or Related Designation.
Al-Pure ..	White	LM-0	DTD 478
Al-Cu	Green	LM-12	LAC 10
	Green and white ..	LM-11	DTD 304
	Green and blue ..	LM-19	DTD 294
Al-Mg	Black	LM-5	DTD 165
	Black and white ..	LM-10	DTD 300A
Al-Cu-Ni (Fe, Si)	Brown	LM-7	DTD 133C
	Brown and black..	LM-14	"Y" alloy
	Brown and white	LM-15	RR 53
Al-Zn (Cu) ..	Blue	LM-1	DTD 428
	Blue and black ..	LM-3	LAC 113B
Al-Si (Mg) ..	Yellow	LM-6	L.33
	Yellow and white	LM-18	ALAR 00·5
	Yellow and green	LM-20	ALAR 00·12
	Yellow and red ..	LM-8	AC.8
	Yellow and brown	LM-9	DTD 240/5
	Yellow and black	LM-13	Lo-Ex
	Yellow and blue ..	LM-17	Birmasil Special
Al-Si-Cu ..	Red	LM-4	DTD 424
	Red and white ..	LM-2	LAC 112A
	Red and black ..	LM-16	DTD 272/6
	Red and green ..	—	ALAR 305
	Red and blue ..	—	ALAR 308

with the result that alloy manufacturers are sometimes required to paint one alloy with varying colours or two or more alloys with the same colour to meet the wishes of different founders. To overcome this lack of uniformity and so avoid possible confusion in the production and storage of alloys, the members of Alar have agreed to the standard system of colours set out in the table herewith. The compilers hope that all founders who prefer this method of identification will co-operate by accepting the new colour scheme. They emphasise, however, that this standardisation is not an attempt to popularise identification by colour and that the other methods which have been used in the past will be continued unless the founders concerned desire the change.

DEVELOPMENTS IN NOTCH-BAR TESTING.

(*Concluded from page* 746.)

WE conclude below our report of the remarks by Dr. N. P. Allen, Superintendent, Metallurgy Division, National Physical Laboratory, who, as *rapporteur* of the symposium held in London on December 5, on the subject of "Recent Developments on the Notch-Bar Testing of Materials and their Relation to Welded Construction," gave, in brief outline, the main points put forward by the authors of the papers presented. At the afternoon session of the symposium, when dealing with the papers by Mrs. C. F. Tipper, M.A., Sc.D., on "Notch-Bar Tests in Relation to Service Performance" and by Dr. J. H. van der Veen on "Development of a Testing Method on Brittle Fracture of Mild-Steel Plates," Dr. Allen's remarks were as follows.

DR. N. P. ALLEN'S REPORT.

These two papers have this in common: that they are both by authors who have an improved test to advocate, and both these tests are designed to be carried out on steel plate and are static tests, into which the element of impact does not enter. Mrs. Tipper is not concerned primarily in describing her test, but she discusses the subject of notched-bar testing generally, and draws attention to cases in which her test appears to have estimated correctly the degree of danger of brittle fracture, and other tests might perhaps have led to the conclusion that the margin of safety was greater than it proved to be. In the first part of her paper, she deals with the characteristics of the fractures of plates in service and points out that the plastic deformation, which may be either much or little, is confined to a very narrow zone, and that when cleavage fractures occur the local deformation and the energy absorbed in fracture are very low. She distinguishes, as others have done, between the energy absorbed in the initiation of a fracture and that required for its propagation, and agrees with Mr. Boyd that tests on small specimens are apt to over-estimate the importance of the initiation energy. Consequently they over-emphasise the importance of the shape of the notch that initiates fracture relative to that of the energy absorbed in propagating the crack. Mrs. Tipper would prefer large specimens as large as practical considerations allow, and states that in the notched tensile test the width of the specimen should not be less than twice the thickness of the plate.

Cases in which failure in practice can be correlated with the results of notched-bar tests are fortunately rather rare, but the U.S. Bureau of Standards have examined a number of cracked plates from ships and have obtained results from which it has been concluded that there is danger of brittle fracture in ship steel if the energy absorption is less than 15 ft.-lb. at a temperature of 60 deg. F. in a standard V-notched Charpy impact test. It is emphasised that it is not known how much greater the notch toughness must be to remove the danger. Two cases are quoted of failures in ship plate in which the temperature at which the failure occurred is known. In both these cases the temperature of failure agreed with the temperature of transition from a shear to a cleavage fracture as observed in an internally-notched 12-in. wide plate. In one of these cases the steel was also classified as brittle by a V-notch Charpy test. In this paper two new cases are described. One relates to fractured plates in a refrigerated cargo ship, in which the temperature of the cargo space was — 11 deg. C. The Izod impact values at — 11 deg. C. of the plates containing the crack, and the upper limit of the transition temperature as determined in the notched-tensile test, are given in Table I. The Izod impact values are com-

TABLE I.

Ref. No.	Izod, at 11 deg. C.	Percentage Crystalline in Fracture.	Upper Limit Temperature Transition Notch Tensile.
	ft. lb.		Deg. C.
A 1 .. }*	40-50	80	0 to — 10
2 .. }*	35-40	100-60	0 to — 10
B 1	35-40	75-80	— 16 to — 20
3 A .. }*	30-35	Patches C.	— 10 to — 16
4 1 .. }†	30-40	75	—

* A 1, 2, 3 A and 4 1 are from different positions in same plate. A 1, 2, and B 1, are test samples cut in direction of rolling. 3 A is a sample cut transverse to direction of rolling.

† 4 1 figures supplied by Mr. W. E. Lewis, B.Sc., Lloyd's Register of Shipping.

fortingly high, but the notched tensile tests indicate that two of the plates at — 11 deg. C. are within the danger zone and the others very near. In this case the notched tensile test has given the better impression of the potential danger. The second case refers to ship plates which cracked during rough weather at 10 deg. C. (50 deg. F.). In this case both the Izod test and the notch tensile test classified the steel as brittle at the temperature at which failure occurred.

Finally, Mrs. Tipper gives Izod and notched-tensile test results over a range of temperatures, relating to a Swedish steel in two conditions of treatment. We are not told what the steel is, nor what the treatments are, but the results pose this question : are we to judge by the energy absorbed or by the nature of the fracture ? If we rely on the energies, and certainly if we confine our tests to temperatures above — 40 deg. C., we shall conclude that one of the steels is the better material, whereas if we consider the fractures we shall conclude that the other is the better. Mrs. Tipper would like us to agree that the lower energy absorption when coupled with a fully fibrous fracture is to be preferred to a higher energy absorption that is accompanied by traces of cleavage failure in the fracture.

The paper by Dr. van der Veen is a very lucid account of a test that was evolved at the Royal Netherlands Steelworks for the purpose of controlling and improving their fabricating procedures. His approach is worth noting. He regards notch toughness, or the resistance to the spread of a crack, as the last safeguard to the security of a structure after design and fabrication procedures have failed to provide conditions that avoid the production of a crack. Since such cracks spread with very little deformation, it is essential that the initial crack be produced very early in the test before any substantial amount of deformation has occurred, and that much of the time occupied by the test be concerned with the spread of the crack. Shock loading is to be avoided, since shock plays no part in the failure of normal welded structures, and the test must be designed to include the full thickness of the plate.

After some preliminary trials, from which it emerged, among other things, that no consistency is to be expected from tests on samples with sheared edges, a bend test on a wide beam with a small, sharp, pressed-in notch was chosen, and load deflection curves were automatically recorded. A fully tough plate shows a load deflection curve which declines smoothly from the maximum load to zero, and a fracture which is completely fibrous. A less tough plate shows at some stage a sudden drop in the resistance of the plate, accompanied by the appearance of a crystalline area in the fracture, which is generally followed by a small fibrous area near the top edge. As the brittleness of the sample increases, the sudden drop appears earlier in the test, and the area of the crystalline fracture increases.

The quantities that may be measured are: the maximum load; the deflection at the maximum load; the energy absorbed at the maximum load; the energy absorbed after the maximum load; the ratio of the load, at which cleavage occurs, to the maximum load; the length of the fibrous fracture path; the energy in the "tail" of the fracture; and the width of the "thumb-nail" area where fibrous fracture is resumed at the end of the test.

The fracture at the root of the notch generally begins when the load is about half-way between the yield load and the maximum load. The first group of quantities relates to the tendency of the crack to be a cleavage crack from the beginning, since if cleavage begins at once these three quantities will all be lower than usual. The second group relates to the point at which an initial fibrous fracture changes to a cleavage fracture, which may occur either in the tension half of the test-piece or in the compression half. It is rather unusual for the change to take place at the neutral axis. The reason for this is believed to be that the neutral axis undergoes little plastic deformation, and plastic deformation assists the initiation of the cleavage crack. The third group of quantities relates to the ability of the material to stop the advance of a cleavage crack. The material therefore undergoes three examinations : first, for its tendency to initiate a cleavage crack in a region of local triaxial stress ; second, for its ability to convert a shear fracture into a cleavage crack when the material has previously undergone some plastic deformation, first in tension and then in compression ; and, finally, for its ability to stop a cleavage crack. The factors relating to the stopping of a crack have not yet been studied in detail.

Two critical temperatures are distinguished. The first is the temperature below which the crack is a cleavage crack practically from the beginning. This is defined as the temperature at which the deflection at fracture is half the deflection at maximum load in the tough condition ; or, alternatively, as the temperature at which the breaking load is half-way between the yield point and the maximum load in the tough condition. The value of this critical temperature is dependent on the geometry of the notch. The second critical temperature is that below which the cleavage crack appears in the tension side of the specimen, i.e., when the length of the fibrous fracture is less than 32 mm. This is also approximately the temperature at which the load when cleavage begins is half the maximum load. It is thought to be a temperature at which the ability of the material to propagate a shear fracture undergoes a significant change. It will be seen that the first transition temperature is generally about 15 deg. C. lower than the second.

The actual energy required to start the crack plays no part in these criteria. Dr. van der Veen is therefore among those who discount the forces necessary to produce the fracture and lay all their emphasis upon the type of fracture and the way in which it is propagated. In theory, one could have two materials, one ten times stronger than the other and both behaving alike in this test ; but this is not a valid objection to the test, provided its use is limited to comparing materials of the same general type or provided any differences in strength are taken into account separately. As described, the test is rather elaborate, but it can also be used as a simple control test by choosing one suitable test temperature and using the energy up to maximum load, the deflection at maximum load, the energy after maximum load and the depth of the fibrous area under the notch as figures of merit.

Some comparisons with other tests are given, employing both methods of use. These include comparisons with the Kommerel test and the Kinzel test, in which the initial crack is produced by laying a bead of weld metal on the surface and, in the case of the Kinzel test, by cutting a notch which ends in the heat-affected zone of the weld. When used to define a transition temperature, the test appears to be about as severe as a Kommerel test, and a little less severe than a Kinzel test or a V-notch Charpy test. The results of comparisons between Dr. van der Veen's tests and some other widely used tests are also given. In this case a large number of tests were made by each method, but at one temperature only, and eight 1-in. thick mild-steel plates were used. They were considered to be a series with gradually increasing susceptibility to brittle fracture, the variations being obtained by varying some conditions of manufacture. It is considered that the slow notched bend test discriminates much more sharply than the other tests between the good and the bad plates and that the probability of being misled by a single test is much less in the slow notched bend test. It will be noticed, however, that very widely discrepant results can be obtained in borderline cases.

THE COUNCIL OF THE ROYAL SOCIETY.—It is announced that the following have been elected officers of the Royal Society, Burlington House, London, W.1, for the ensuing year. The President is Professor E. D. Adrian, O.M., the treasurer and a vice-president, Sir Thomas Merton, the secretaries and vice-presidents, Sir Edward Salisbury, C.B.E., and Sir David Brunt, and the foreign secretary, Sir Cyril Hinshelwood.

FRICTION AND SURFACE DAMAGE OF NON-METALLIC SOLIDS.*

By F. P. BOWDEN, Sc.D., F.R.S.

SINCE this new and beautiful Institute is concerned with the properties of rubber, including its friction and wear, I thought it might be appropriate to discuss briefly some of the work we have been doing recently in the Research Laboratory for the Physics and Chemistry of Surfaces of the Department of Physical Chemistry, at the University of Cambridge, on the friction and surface damage of non-metals. I should say at the outset that we have not studied rubber, partly because we have not had the courage to tackle such a complex material and partly because the problem is being so ably dealt with by members of the Rubber Stichting and analogous institutes.

Although we have a working knowledge of the frictional behaviour of metals, our understanding of the physical processes that occur during the sliding of non-metals is far from complete. We shall see, I think, that the general mechanism of the friction of non-metals bears, in certain respects, a close resemblance to the frictional behaviour of metals, but there are interesting and important differences.

May I first remind you of some of the important factors in the friction of metallic surfaces ? The first point is concerned with the real area of contact between metals. We know that metal surfaces, and most other solid surfaces as well, have surface irregularities on them which are large when compared with molecular dimensions. When the solids are placed together they are supported on the summits of these irregularities, so that the real area of contact A is necessarily very small ; hence the pressure, even with lightly loaded surfaces, is very high and is sufficient to cause deformation of the hardest metals. The regions of contact flow plastically under this high pressure until the area A is sufficient to support the load W. We may write

$$A = \frac{W}{P_m}$$

where P_m is the yield pressure of the metal.

Beyond the immediate region of contact the metal will be elastically deformed, the friction representing, in the main, the force F, required to shear these regions of contact, so that $F = As$, the factor s being the shear strength of the material. This would explain the two basic laws of friction, since the real area of contact A is independent of the apparent area of the surfaces and is directly proportional to the load.†

In addition, the surface irregularities of the harder metal may penetrate the softer one so there may be a "ploughing" term, P, representing the work required to plough out the solid in the path of the slider ; but, with metals, this factor is generally small and frequently may be neglected. With non-metals, under appropriate conditions, we may expect this ploughing term P to be important ; with a sharp-pointed irregularity which penetrates a rubber surface, for example, the ploughing term might be larger than the shearing term. It would be interesting to know whether any quantitative measurement of this has been made.

In general, with a metal, because of the work-hardening which takes place in the region of contact, the shearing occurs not at the interface but at a little distance from it, so that small fragments of one metal are left adhering to the other. The existence of this can be demonstrated by radio-active tracer and other methods. If this localised welding occurs between the metals when they are in contact under an applied load, it might be expected that, when the load is removed, the surfaces should continue to adhere and that an appreciable normal force will be required to separate them. If, however, this experiment is performed with reasonably hard metals, such as steel and copper, no evidence is found of any such adhesion. The explanation suggested is a simple one. Although the metal is deformed plastically at the points of contact, there will be elastic deformation in the bulk of the adjacent metal. When the load is removed, these elastic stresses will be released and the resulting displacement will break any junctions that may have been formed. This view is confirmed by experiments with soft metals, such as indium and lead, where the released elastic stresses are very much less. In fact, it is found that, with these soft metals, the normal force required to separate the surfaces is very nearly the same as the tangential force required to slide them ; that is to say, the coefficient of adhesion and the coefficient of friction are approximately the same.‡ The effect of a lubricant film, even of a monolayer, will reduce the adhesion to a very small value. There

* Paper presented at the International Conference on Abrasion and Wear, held at the Rubber Stichting, Delft, Holland, on November 14 and 15, 1951.

† *The Friction and Lubrication of Solids*, by F. P. Bowden and D. Tabor. Clarendon Press, Oxford, 1950.

‡ J. S. McFarlane and D. Tabor, *Proc. Roy. Soc. A.* vol. 202, page 244 (1950).

is, therefore, a close correlation between friction and adhesion.

The second observation on metals that I want to stress is the influence of oxide and other surface films. If the metals are put in a high vacuum, and the surface films which are normally present are taken off, the friction rises to an extremely high value; in fact, complete seizure of the metals occurs when they are placed in contact. An attempt to slide them increases the area of contact and may cause a large-scale seizure. There is evidence that the reduction in friction by air or other gases is due not only to a chemisorbed film, but that the physical or van der Waals adsorption on top of this can further reduce the friction.* How far do these considerations apply to non-metals?

Let us see how a very hard solid like diamond behaves under similar conditions. With diamond sliding on diamond, Amontons' law does not hold; the coefficient of friction is not independent of the load. The reason for this is obvious: with metals, the area of contact is proportional to the load because plastic deformation occurs in the region of contact and $F = k_1 W$. With diamond there will be very little plastic deformation; most of the deformation will be elastic, so that, as a first approximation, the area of contact will be proportional to $W^{\frac{2}{3}}$, and $F = k_2 W^{\frac{2}{3}}$. Experiment shows that, if F is plotted against W for diamond, we get a relationship

$$F = kW^{0 \cdot 8}$$

and it is clear that the deformation in the region of the contact is largely elastic. In the case of a very elastic solid like rubber, we might expect an analogous relationship. I would be interested to hear whether this is so.

What happens if we measure the friction of diamond *in vacuo* when we have driven off the adsorbed films which are normally present? The experiment is more difficult to do than the experiment with metals. The friction of diamond sliding on itself in air is very low ($\mu = c. 0 \cdot 05$). *In vacuo*, however, it rises to a high value ($\mu = 0 \cdot 6$ or more).† If a trace of air or of oxygen is admitted, the value falls again. There is evidence (as with metals) that the effect is due partly to a chemisorbed film of oxygen and partly to a van der Waals film on top of this.

If it be assumed that the area of contact between the diamond surfaces is determined primarily by elastic deformation, we may calculate the shear strength of the junction between the two clean diamond surfaces from the measured value of the friction. Such calculations show that it is approximately 1,200 kg. per square millimetre. This is comparable with the shear strength of solid diamond. These calculations are necessarily approximate, but they suggest that there is strong bonding between the clean diamond surfaces.

Although the bonding is strong, large-scale seizure does not occur on sliding as it does with metals. This is because the deformation of the diamond is essentially elastic, so that the area of contact does not progressively increase during sliding. If, however, a clean metal is slid on a clean diamond surface, plastic flow of the metal can occur. In this case, the area of contact can continue to increase and the coefficient of friction rises to a high value. For example, in some recent experiments, Rowe has measured the friction of a small curved diamond slider on platinum and copper at a load of 25 *g*. In air the coefficient of friction on copper is $\mu = 0 \cdot 4$ and rises on degassing in a vacuum to over $\mu = 1 \cdot 5$. With platinum, the effect is more marked still; the friction of the diamond slider on degassed platinum was greater than $\mu = 3$. The frictional behaviour of sapphire† resembles that of diamond in that it is low when measured in air, but high ($\mu = 0 \cdot 6$ or more) *in vacuo*.

Analogous experiments have been carried out with carbon and with graphite. Again it is found that the low friction normally observed with these materials is due to chemisorbed and to van der Waals adsorbed films of gas and vapour.‡ The frictional results are in harmony with Savage's§ earlier observation on the wear of graphite.

A simple but very important point emerges from all these observations. The frictional behaviour of so-called "clean" non-metallic solids, as we normally study them, is determined more by the presence of the surface films than by the nature of the solid itself. This is probably true also for rubber, where we may expect the surface films to be abundant, various and difficult to remove.

Recently, Dr. K. V. Shooter and Dr. D. Tabor have been making a study of the frictional behaviour of some plastics. In some ways, these substances are useful for the study of friction because we can vary their physical properties over a wide range. The frictional behaviour of a group of structurally related polymers was investigated over a range of loads from $0 \cdot 04$ to 10,000 gm. The measurements were made at low speeds of sliding. Polymers such as polyvinyl chloride, polymethylmethacrylate, polystyrene, polyethylene, polytetrafluoroethylene and also nylon were studied.

It was found that, at light loads, Amontons' law did not hold—the coefficient of friction increased as the loads became lighter. The reasons for this are interesting, but there is not time to discuss them here. Over a range of loads from 100 to 10,000 gm., however, Amontons' law did hold and the coefficient of friction remained constant. The behaviour was very similar to that observed with metals and the real area of contact was again given by the expression $A = \frac{W}{p}$, where p (by analogy with metals) can be called the "effective yield pressure" of the plastic. It was found that, over this range of loads, the frictional force was proportional to the area of contact. Again we can write $F = As$; experiment showed that the shear strength s of the junction, as determined from the friction, was in reasonable agreement with the measured shear strength of the bulk plastic.

Detailed examination of the surface damage showed local adhesion and welding, with transference of the solid from one surface to another; and it is clear that the whole process of sliding is, under these conditions, closely analogous to that obtaining with metals. An account of some of this work was given at the recent Royal Society Discussion on Friction. The plastic polytetrafluoroethylene has a very low friction ($\mu = 0 \cdot 04$) and this appears to be an inherent property of the material, since measurements made by R. F. King show that the friction remains low even in a high vacuum.

Finally, I should like to say a word about the surface temperatures developed on sliding metals and non-metals. In the case of metals, we may measure the temperature in a simple way by using two different metals as a thermocouple,* and measuring the thermo-electric potential developed on sliding. Experiment shows that temperature flashes of 1,000 deg. C. or so occur, even at moderate speeds of sliding. The results are in reasonable agreement with theory. The temperature rise is proportional to the square root of the load, as theory suggests, and also, with a metal of low thermal conductivity, such as steel, hot spots are reached more easily than with good conductors like tungsten. Now with non-metals, such as glass, plastics, and rubber, we should expect the temperature rise to occur more easily still. We cannot use the thermo-electric method, but we may use others. One of these is the photographic one,† the other is the use of infra-red cells. Both of these methods show how readily high temperatures are reached on non-conductors. Even when the sliding speed is only one or two feet per second, the local regions of contact between the sliding surfaces may be red hot. I suspect that these local high temperatures can play an important part in the friction, wear and abrasion of rubber.

* F. P. Bowden and J. E. Young, *Proc. Roy. Soc. A*, vol. 208, pages 144 and 311 (1951).

† G. W. Rowe, *Royal Society Discussion on Friction*. (In the press.)

‡ F. P. Bowden and J. E. Young, *loc. cit.*

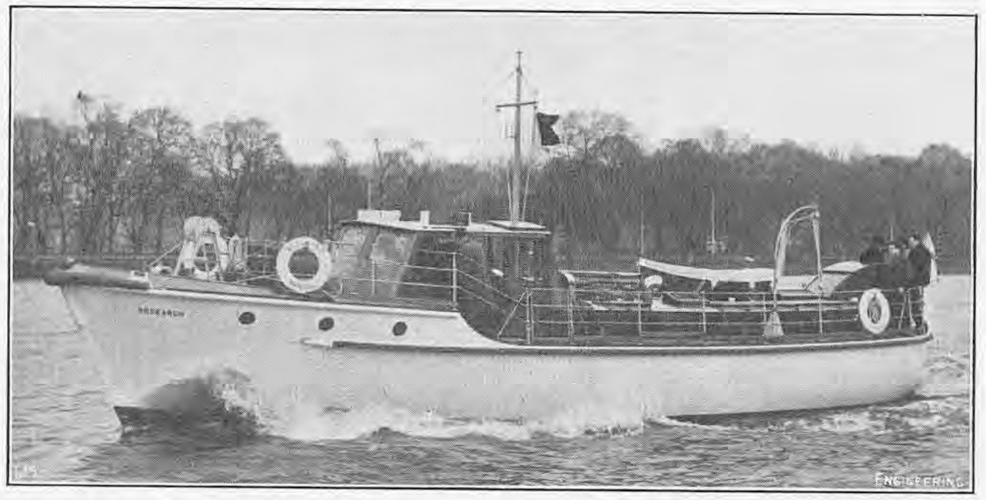
§ R. H. Savage, *Jl. App. Physics*, vol. 14, page 1 (1948).

* F. P. Bowden and K. E. W. Ridler, *Proc. Roy. Soc. A*, vol. 151, page 610 (1936); and M. A. Stone and G. K. Tudor, *ibid.*, vol. 188, page 329 (1947).

† F. B. Bowden and K. E. W. Ridler, *loc. cit.*

SURVEY LAUNCH FOR PORT OF BRISTOL.

JOHN I. THORNYCROFT AND COMPANY, LIMITED, LONDON.



53-FT. SURVEY LAUNCH FOR PORT OF BRISTOL AUTHORITY.

CONTRACTS completed recently by Messrs. John I. Thornycroft and Company, Limited, Smith-square, London, S.W.1, include the motor survey vessel Research, which was built at their Hampton-on-Thames yard for the Port of Bristol Authority. The Research, a photograph of which is reproduced herewith, will be employed mainly in the Port of Bristol area for taking soundings and recording the movements of sand and mud banks. She has a length of 53 ft., a beam of 12 ft. and a draught of approximately 3 ft. 9 in. The hull, which is of the round-bilge form with a raked stem and canoe stern, is made from mahogany planking laid on closely-spaced steam-bent oak timbers. The under-water portion of the hull is sheathed in Muntz metal to approximately 4 in. above the water-line, and to obtain good stability during survey operations, bilge keels are fitted.

The launch is propelled by two Thornycroft RTR6 Ricardo-type Diesel engines, each capable of developing a maximum output of 65 h.p. at 2,250 r.p.m.; for the Research, however, the engines have been de-rated to a maximum of 55 h.p. at 2,100 r.p.m., sufficient to give the launch a speed of about 9½ knots. Oil-operated reverse gears incorporating a reduction of 2 to 1 are installed; these were manufactured by the Self-Changing Gear Company, Limited, Coventry, and are fitted with the Thornycroft combined clutch-and-throttle control system. This employs a single lever for each gearbox, arranged to control both ahead and astern motion and engine speed, thus simplifying manœuvring and ensuring that the engines are throttled back before the clutches are either engaged or disengaged. As the vessel will operate frequently in silty waters, the stern tubes are fitted with special sand-excluding glands and the engines cooled by a closed fresh-water system operating in conjunction with external heat-exchangers. One engine is provided with a mechanically-driven bilge pump connected by means of a valve chest to the four compartments of the launch, and there is also a hand-operated semi-rotary pump for use when the engines are shut down.

The surveying equipment installed in the vessel includes an echo-sounder and means for measuring the distance from the shore when it is required to plot a position with particular accuracy. This consists of a drum of wire carried on a measuring wheel and arranged so that one end can be anchored ashore and the wire paid out from the drum to the required length. A leadsman's platform is installed at the starboard side of the foredeck and, as much of the surveyor's work will be carried out from the wheelhouse, this is enclosed all round with glass windows so as to give clear vision. In the roof of the wheelhouse there is a sliding hatch at each side with a hinged platform near the floor so arranged that the surveyor can stand with his head and shoulders exposed when necessary. The accommodation includes quarters for the crew, fitted with locker seats and portable mattresses, and a main saloon. The latter compartment is intended mainly for use by the Docks Committee when on port inspections and is furnished with cushioned locker seats, tables and storage lockers. A 9-ft. pulling dinghy is carried over the top of the saloon and suitable sockets are installed at each side of the deck to accept portable davits. A store for the surveyor's equipment is situated below the wheelhouse, access being gained through a hatch in the wheelhouse deck.

240/180-B.H.P. DUAL-FUEL ENGINE.

RUSTON AND HORNSBY, LIMITED, LINCOLN.

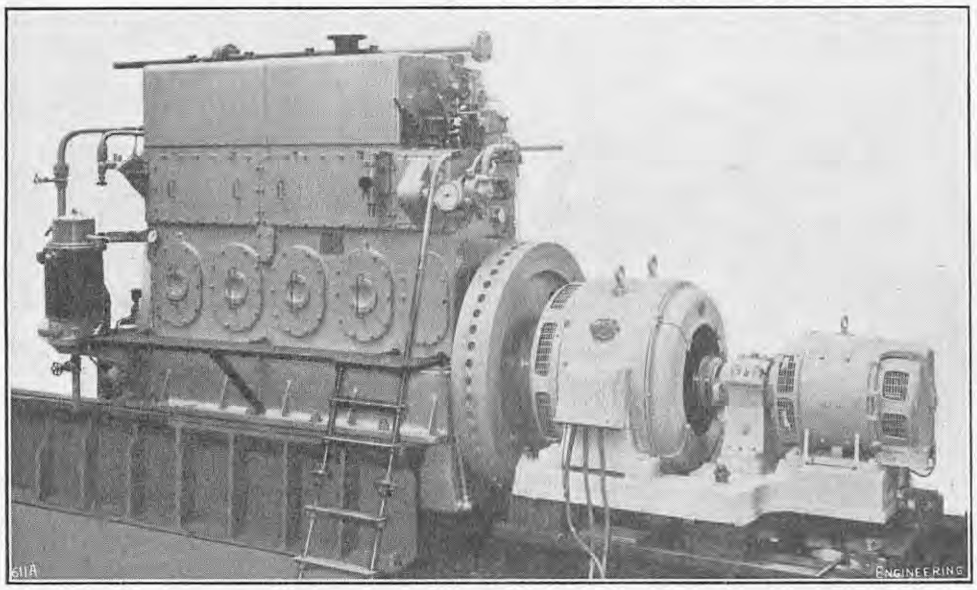


FIG. 1. 240/180-B.H.P. ENGINE COUPLED TO GENERATOR.

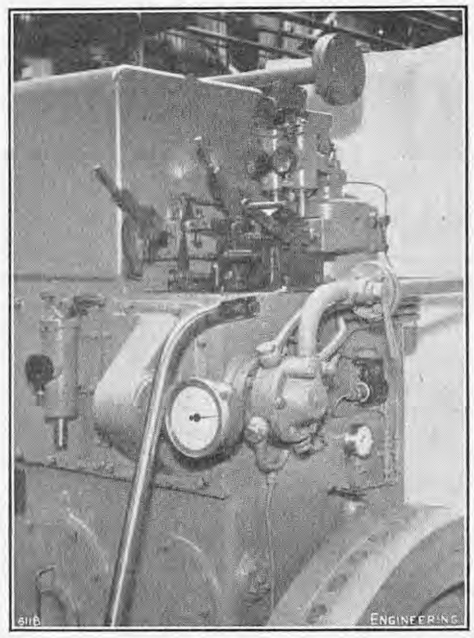


FIG. 2. CONTROL GEAR.

NEW RANGE OF DUAL-FUEL ENGINES.

ALTHOUGH Messrs. Ruston and Hornsby, Limited, Lincoln, are well known as the manufacturers of heavy-oil engines, it is perhaps not so widely known that they are now producing a range of dual-fuel engines. This field is, of course, not new to Ruston and Hornsby, as they were producing such engines before the Second World War. Owing to the need, however, to meet the requirements of the Services during the war, and subsequently to concentrate on the rebuilding of their organisation for the production and marketing of oil engines, the dual-fuel engine programme was left largely in abeyance. Nevertheless, market research has shown that there is a growing demand for these engines, particularly overseas and, as a consequence, the firm have developed limited ranges of horizontal and vertical engines designed to operate on oil fuel or natural, town's, sewage or suction gas. All engines in the two ranges are based on the firm's current designs of oil engine; they bear, therefore, little relationship to the original pre-war products as they embody all the improvements and refinements made possible by later research.

At present, the outputs, when operating on gas, range from 39 brake horse-power to 225 brake horse-power for the horizontal engines, and from 116 brake horse-power to 270 brake horse-power for the vertical engines. In every case, the engine starts on oil, change-over to gas being effected by movement of a single lever after the main gas valve has been opened. This automatically reduces the fuel supply to approximately 10 per cent. of the normal charge and connects the governor into the gas supply, the flow of which is regulated by a linkage joining the governor actuating mechanism to a butterfly-type gas valve. In most respects, the dual-fuel engines are similar to their oil-engine counterparts, the only modifications of note being made to the cylinder heads and induction systems, but in some cases, it has proved possible to use the same design of cylinder head for both types of engine.

A typical dual-fuel engine is illustrated in Figs. 1 and 2, on this page, Fig. 1 showing a general view of the engine and associated generator and Fig. 2 the control gear. This is a four-cylinder unit having a bore and stroke of 10½ in. and 14½ in., respectively, and developing 240 brake horse-power when operating on oil and approximately 180 brake horse-power when used as a dual-fuel unit, the actual output depending, of course, on the calorific value of the gas. Five- and six-cylinder engines of the same general design are also available, the five-cylinder engine developing 300 h.p. and 225 h.p. on oil and dual fuels, respectively, the corresponding figures for the six-cylinder version being 360 h.p. and 270 h.p., the dual-fuel ratings being approximate only in each case. The engine illustrated in Fig. 1 is of straightforward construction and follows the firm's standard practice. The bedplate, crankcase and cylinder block are separate castings, the crankcase portion having large inspection doors which give good access to the running gear and incorporate relief valves for protection against crankcase explosions. A solid crankshaft machined from a steel forging is used; it is supported by five main bearings of the steel-backed whitemetal-lined type. The connecting rods are also machined from steel forgings and are joined to the crankshaft by whitemetal-lined big ends and to the pistons by phosphor-bronze bushes. A special heat-resisting material is used for the pistons, each of which is provided with five pressure rings and a single oil-control ring.

The main difference between this unit and a normal oil engine is in the design of the cylinder heads. These are cast separately and each has a divided inlet port for the admission of gas and air, respectively, each air-inlet valve having a gas valve incorporated on its stem. The valves are operated in the usual manner by push rods and rocking levers from a camshaft set fairly low in the engine and driven by a chain from the flywheel end of the crankshaft. Removable valve guides and seats are fitted, the latter being of special heat-resisting cast iron and the exhaust valves of heat-resisting steel. The air manifold is embodied in the engine housing but the gas manifold is an independent fitting which is connected to the cylinder heads by means of elbow pieces, one for each cylinder. The gas manifold is arranged to carry the governor-operated control gear and each elbow has two passages, one for air and the other for gas, both of which are fitted with butterfly valves for regulating the flow of air and gas respectively. These valves, as previously indicated, are connected to the governor control linkage when the engine is operating on gas.

When running on gas, the ignition of the main air-gas charge is effected by means of an oil-fuel ignition charge ignited by the heat of compression in the normal manner. A hand-operated lever controls the oil-fuel supply for starting and running, the maximum charge being used for starting, regardless of whether the engine is operating as an oil or a dual-fuel unit. When the gas cock is opened, the governor automatically reduces the charge of oil which, at working load, is normally 10 per cent. of that required when operating on oil alone. The power developed by the engine illustrated is 240 brake horse-power when operating on oil only, the brake mean effective pressure being 79·4 lb. per square inch. With producer gas the output is approximately 180 brake horse-power, provided the calorific value is not less than 135 B.Th.U. per cubic foot, and that the suction is not greater than 6 in. water gauge; should the suction be more than this, then a booster must be fitted. All these ratings refer to an engine speed of 500 r.p.m.

In general, the modifications required to be carried out on a horizontal engine are similar to those on the vertical engine just described, the details depending on the size and type of the unit. As in the case of the vertical engines, horizontal engines required to operate as dual-fuel units are fitted with a modified design of cylinder head having a divided inlet port for the admission of gas and air, admission of the former being controlled by a gas valve integral with the inlet-valve spindle. A divided air-gas manifold is fitted to the inlet connection to the cylinder head, the manifold being arranged to carry the governor-operated control gear. With the gas valve incorporated in the cylinder head, the mixing of air and gas takes place immediately before entry to the combustion chamber, as on the vertical engines. The injection equipment also is changed, helix-type fuel pumps, as used on the vertical engines, being fitted in place of the spill-valve type pump, and the distributor normally fitted to two- and four-cylinder engines is replaced by multiple fuel pumps.

TRADE PUBLICATIONS.

Mechanical-Handling Equipment.—Steels Engineering Products, Ltd., Crown Works, Sunderland, have issued leaflets describing their electric tractor, trucks, hoist blocks, etc.

Woodworking Machinery.—Many types of wood-working and veneering machines are included in a catalogue produced by F. J. Edwards, Ltd., 359-361, Euston-road, London, N.W.1.

Compressed-Air Operation of Controls.—The principles and advantages of their valves, cylinders, etc., for the pneumatic operation of controls on machines are described in a booklet prepared by the Climax Rock Drill and Engineering Works, Ltd., Carn Brea, Redruth, Cornwall. Some typical applications are described.

Electrostatic Air Filters.—The Sturtevant Engineering Co., Ltd., Southern House, Cannon-street, London, E.C.4, have issued a fresh booklet on their Precipitron electrostatic air filters, which have been fitted in the new House of Commons and many other buildings. It contains a brief technical report on the subject, including an interesting "dust spectrum," which gives the range of particle sizes of typical aerosols, industrial dusts, and other disperse systems, in conjunction with the ranges of commercial plants for dust removal, and other useful data on the particles.

Air-Compressor Plant.—The English Electric Co., Ltd., Queen's House, Kingsway, London, W.C.2, have published an illustrated brochure describing the constructional features and performance of their air-compressor plant, which are designed primarily for use with air-blast circuit breakers but are suitable for many other applications. The plant, which comprises either one or two compressor units mounted on a horizontal receiver, with ancillary and control gear, is available for working pressures ranging from 250 lb. to 600 lb. per square inch, with corresponding capacities of 7·1 cub. ft. and 17·5 cub. ft. of free air per minute.

Very-High-Frequency Direction-Finding Equipment.—We have received from Marconi's Wireless Telegraph Co., Ltd., Marconi House, Chelmsford, a leaflet describing their AD200 very-high-frequency direction-finding equipment for air-traffic control, which presents the aircraft bearing, to the ground operator, with an error not exceeding 2 deg. on well-sited systems, instantaneously on an 8-in. dial, either locally at the aerial site, or, through standard telephone lines, at remote stations up to 30 miles away from the aerial. Two channels may be operated from one aerial system. The frequency range is from 118 to 132 mega-cycles per second; the receiver band-width is ± 2 kilocycles per second. The equipment operates from 110/130-volt or 200/250-volt 50-cycle mains.

NOTES ON NEW BOOKS.

Measurement and Correction of Lead Screws.

The Director, National Physical Laboratory, Teddington, Middlesex. [Free and post free.]

HENRY MAUDSLAY invented the screw-cutting lathe, and his first machine, constructed in 1805, is now in the Science Museum at South Kensington. One of the first uses to which he put it was the production of lead screws for other lathes, and within a year he had improved their accuracy to a point which represented one of the most important single developments in mechanical engineering. The accuracy of lead screws is still a fundamental requirement, and the correction of such screws to fine limits—a maximum departure from the true pitch between any two points on the screw of 0·0002 in. over any foot length, or 0·0005 in. over any length between 3 ft. and 5 ft.—is one of the major contributions of the National Physical Laboratory to the engineering industry. The present pamphlet (No. 8 in the series of Test Pamphlets issued by the Department of Scientific and Industrial Research) describes and illustrates the method, specifies the pre-finish required on screws sent to the National Physical Laboratory for correction, and contains tables of fees for this work and for the measurement of pitch error on screws not corrected by the Laboratory.

The Fundamental Principles of Road Passenger Transport Operation.

By FREDERICK G. FLETCHER, A.M.Inst.T. Macdonald and Company (Publishers), Limited, 16, Maddox-street, London, W.1. [Price 21s. net.]

THIS book, the author states, has been written to help young passenger-transport "operators"—a term which is intended, apparently, to include "drivers, conductors, officials or clerks"—to learn the elements of their occupation and to assist them to qualify for the certificates and diplomas of the Royal Society of Arts and for admission to the Institute of Transport. Mr. Fletcher is a district superintendent of London Transport's road services, and lecturer on road passenger transport operation at the North-Western Polytechnic and at Tottenham Technical College, and has based his book on lectures given at those colleges. The result is a work which is likely to be read with interest by many others, however, than those to whom it is primarily addressed; and if some find it rather elementary in places, they should bear in mind that it is intended to be so. The outcome of their reading, however, will be almost certainly a better appreciation of British road passenger transport, its problems, and the comparative simplicity of its fare systems and methods of fare collection. Most of the complicated foreign systems described and illustrated would be completely unworkable with the traffic density experienced in London or any large city in the British Isles.

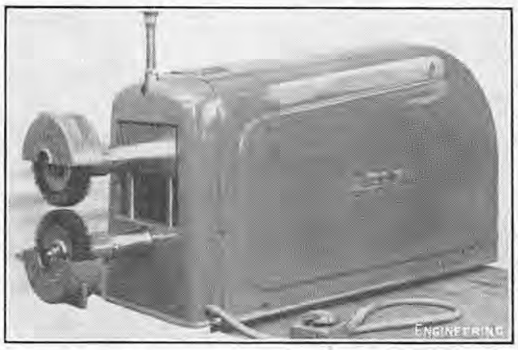
Danger Ahead: The Dramatic Story of Railway Signalling.

By RICHARD BLYTHE. Newman Neame, Limited, 29, Percy-street, London, W.1. [Price 10s. 6d.]

BEFORE 1951 is over we must notice this book on a branch of railway work that has not a very long bibliography; for—as Mr. T. S. Lascelles remarks in an introduction—it is a hundred years since Edward Tyer, then a young man of 21, directed his interest in electrical science to the signalling problems of railways. He was, in due course, the founder of the first business devoted expressly to the manufacture of apparatus for train signalling, though he was one of many—notably C. V. Walker, C. E. Spagnoletti, William Preece and W. R. Sykes—who, in the latter half of the Nineteenth Century, brought order and system to the control of the movement of trains. The scope for inventors of apparatus was broadened as a result of new Acts of Parliament on the Regulation of Railways (the Acts often following serious accidents), and by the railway-inspecting powers of the Board of Trade. Mr. Blythe has taken a wider view of his subject than the sub-title suggests; he has included sketches of the history of related railway and industrial matters, but as his writing has style the reader gains by their inclusion. He has confined himself to British practice, and, in a book intended for the general reader, he has satisfactorily overcome the difficulty of describing the principles of complex mechanical and electrical techniques. Modern developments, such as track-circuiting, power and automatic signalling, colour-light signals, and electric interlocking, are covered. The standard of safety on the railways has always been high—even in 1865, only 23 travellers out of a total of 252,000,000 met with death by "causes beyond their control"—and it has been kept high, in spite of increased speeds and more intense traffic, as a result of the railways' paramount regard for safety, the inspecting powers provided by a vigilant Parliament, and the work of railway-signal engineers.

TWIN-HEAD BRUSHING MACHINE.

THE accompanying illustration shows a twin-head brushing machine, known as the Morrisflex M151, which has been introduced recently by Messrs. B. O. Morris, Limited, Briton-road, Coventry. It is available in two versions, with brushes projecting either 4 in. or 14 in. from the casing. The diameter of the brushes may range from 3 in. to 6 in., with a brush width of



up to 2 in. Either $\frac{3}{8}$-in. or $\frac{1}{2}$-in. bore brushes can be accommodated. The brushes are driven by an electric motor housed within the casing, the motor being controlled by a foot switch which must be kept depressed for continuous running. The motor is fitted with a thermal overload switch. The spindle of the top brush is mounted on a block which can be adjusted vertically by a screw to vary the gap between the two brushes up to $\frac{3}{8}$ in. The guards can be adjusted radially.

LAUNCHES AND TRIAL TRIPS.

M.S. "LEASOWE."—Twin-screw ferry to carry 1,600 passengers, built by Philip and Son, Ltd., Dartmouth, for the Seacombe and Liverpool service of the Wallasey Corporation. Classed and equipped for carrying 700 passengers when on cruising service on the River Mersey. Main dimensions: 145 ft. between perpendiculars by 34 ft. by 12 ft. 3 in.; mean load draught, 7 ft. 4 in. Two eight-cylinder direct-reversible two-stroke Diesel engines, together developing 1,200 b.h.p. at 330 r.p.m., constructed by Crossley Brothers, Ltd., Openshaw, Manchester. Speed, $13\frac{3}{4}$ knots. Trial trip, November 17.

M.S. "THORSKOG."—Single-screw oil tanker, built by the Greenock Dockyard Co., Ltd., Greenock, for A/S Thor Dahl, Sandefjord, Norway. Main dimensions: 542 ft. 6 in. overall by 69 ft. by 38 ft. 6 in. to upper deck; deadweight capacity, 16,500 tons on a mean draught of 29 ft. 9 in.; gross tonnage, 11,400; oil-cargo space, 802,000 cub. ft. Wallsend-Doxford five-cylinder opposed-piston oil engine, developing 5,500 b.h.p. at 112 r.p.m. in service, constructed by Wallsend Slipway and Engineering Co., Ltd., Wallsend-on-Tyne, and installed by Rankin and Blackmore, Ltd., Greenock. Speed, about 14 knots. Trial trip, November 20.

S.S. "BRITISH BULLDOG."—Single-screw oil tanker, built by Swan, Hunter, and Wigham Richardson, Ltd., Wallsend-on-Tyne, for the British Tanker Co., Ltd., London, E.C.2. Main dimensions: 610 ft. between perpendiculars by 81 ft. by 44 ft. 6 in. to upper deck; deadweight capacity, about 28,540 tons on a draught of 33 ft. $11\frac{1}{2}$ in.; oil-cargo tank capacity, 26,875 tons; gross tonnage, 18,000. Steam turbines with double-reduction gearing, developing a maximum of 13,750 s.h.p. at 116 r.p.m., and two Babcock and Wilcox oil-burning boilers, constructed by the Wallsend Slipway and Engineering Co., Ltd., Wallsend-on-Tyne. Speed on service, 15 knots, fully loaded. Trial trip, November 21.

M.S. "COPSEWOOD."—Single-screw cargo vessel, built by the Burntisland Shipbuilding Co., Ltd., Burntisland, Fife, for the Constantine Shipping Co., Ltd., Middlesbrough. Second of two similar vessels. Main dimensions: 214 ft. 6 in. between perpendiculars by 35 ft. 4 in. by 16 ft.; deadweight capacity, 1,675 tons on a draught of 15 ft. $8\frac{1}{2}$ in. Four-cylinder two-stroke trunk-piston directly-reversible Diesel engine, developing 640 b.h.p. at 250 r.p.m., constructed by British Polar Engines, Ltd., Glasgow, and installed by the shipbuilders. Speed in service, 10 knots. Trial trip, November 30.

S.S. "GARLINGE."—Single-screw cargo vessel, built and engined by William Gray & Co., Ltd., West Hartlepool, for Constants (South Wales), Ltd., London, E.C.2. Second vessel of an order for three. Main dimensions: 340 ft. overall by 46 ft. 6 in. by 24 ft. $3\frac{1}{2}$ in. to upper deck; deadweight capacity, 4,628 tons on a draught of 20 ft. 6 in. Triple-expansion steam engines and two oil-fired forced-draught boilers. Speed in service, $10\frac{1}{2}$ knots. Trial trip, November 30.

M.S. "BESKIDY."—Single-screw oil tanker, built by Bartram & Sons, Ltd., Sunderland, for the Gdynia-America Shipping Lines, Ltd., Gdynia, Poland. Second vessel of an order for two. Main dimensions: 445 ft. between perpendiculars by 60 ft. 6 in. by 34 ft. to upper deck; deadweight capacity, about 11,000 tons on a draught of 27 ft. 6 in. N.E.M.-Doxford four-cylinder opposed-piston airless-injection oil engine, developing 4,250 b.h.p. at 110 r.p.m. in service, constructed by the North Eastern Marine Engineering Co. (1938), Ltd., Wallsend-on-Tyne. Speed on trial, $13\frac{3}{4}$ knots. Trial trip, November 28.

M.S. "CROYDON."—Single-screw collier, built by the Burntisland Shipbuilding Co., Ltd., Burntisland, Fife, for the South Eastern Gas Board, Croydon, Surrey. Second vessel of an order for three. Main dimensions: 265 ft. 10 in. between perpendiculars by 39 ft. 6 in. by 18 ft. 6 in.; deadweight capacity, 2,875 tons on a draught of 17 ft. $1\frac{1}{4}$ in.; gross tonnage, 1,871. Eight-cylinder marine Diesel engine, developing 1,150 b.h.p. at 225 r.p.m., constructed by British Polar Engines, Ltd., Glasgow, and installed by the shipbuilders. Speed, about $10\frac{3}{4}$ knots. Trial trip, December 12.

BOOKS RECEIVED.

Productivity Team Report. Coal. Report of a productivity team representing the British coal mining industry which visited the United States of America in 1951. Anglo-American Council on Productivity, 21, Tothill-street, London, S.W.1. [Price 3s. 6d. post free.]

Department of Scientific and Industrial Research. Report of the Forest Products Research Board with the Report of the Director of Forest Products Research for the Year 1949. H.M. Stationery Office, Kingsway, London, W.C.2. [Price 2s. 6d. net.]

Department of Scientific and Industrial Research Advisory Council. Report of the Committee on Chemical Engineering Research. H.M. Stationery Office, Kingsway, London, W.C.2. [Price 1s. 6d. net.]

Department of Scientific and Industrial Research. Report of the Building Research Board with the Report of the Director of Building Research for the Year 1950. H.M. Stationery Office, Kingsway, London, W.C.2. [Price 4s. net.]

Whitaker's Almanack, 1952. By JOSEPH WHITAKER. J. Whitaker and Sons, Limited, 13, Bedford-square, London, W.C.1. [Complete edition, without maps, price 15s.; shorter edition, 7s. 6d. Library edition, bound in leather, with maps, 30s., available in January.]

Road Research. Road Note No. 12. *Gritting Machines for Surface Dressing.* By D. B. WATERS and D. S. WILSON. H.M. Stationery Office, Kingsway, London, W.C.2. [Price 1s. 6d. net.]

The Non-Destructive Testing of Metals. By DR. R. F. HANSTOCK. The Institute of Metals, 4, Grosvenor-gardens, London, S.W.1. [Price 21s.]

Man and the Chemical Elements, from Stone-Age Hearth to the Cyclotron. By DR. J. NEWTON FRIEND. Charles Griffin and Company, Limited, 42, Drury-lane, London, W.C.2. [Price 27s. 6d. net.]

Experimental Spectroscopy. By PROFESSOR RALPH A. SAWYER. Second edition. Chapman and Hall, Limited, 37, Essex-street, Strand, London, W.C.2. [Price 30s. net.]

The Resistance of Piles to Penetration, with Tables of Approximate Values Based on the Hiley Formula. By RUSSELL V. ALLIN. Second revised edition. E. and F. N. Spon Limited, 22, Henrietta-street, London, W.C.2. [Price 21s. net.]

The Design and Placing of High Quality Concrete. By D. A. STEWART. E. and F. N. Spon, Limited, 22, Henrietta-street, London, W.C.2. [Price 25s. net.]

Ministry of Transport. Railway Accidents. Report on the Collision which Occurred on 9th June, 1951, *at Stobcross in the Scottish Region British Railways.* H.M. Stationery Office, Kingsway, London, W.C.2. [Price 2s. net.]

The Directory of Contractors and Public Works Annual, 1951-52. Edited and compiled by C. W. BIGGAR. C. W. Biggar Limited, 93, Western-avenue, London, W.3. [Price 40s.]

Modern Production Control. By A. W. WILLSMORE. Second edition. Sir Isaac Pitman and Sons, Limited, Pitman House, Parker-street, Kingsway, London, W.C.2. [Price 15s. net.]

First Seminar for European Sanitary Engineers. The Hague, 27 November to 2 December, 1950. World Health Organisation, Palais des Nations, Geneva, Switzerland.

Fire Research. Technical Paper No. 1. *The Fire Hazard of Fuelling Aircraft in the Open.* By DR. L. L. KATAN. H.M. Stationery Office, Kingsway, London, W.C.2. [Price 1s. net.]

A Concise Guide to Industrial Relations. Revised for the Industrial Disputes Order, 1951. By T. WYLIE. The honorary secretary, Industrial Administration Group of the Guild of Students of the College of Technology, Suffolk-street, Birmingham. [Price 2s. 6d. post free.]