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THE JOURNAL OF THE ADELAIDE UNIVERSITY ENGINEERING SOCIETY

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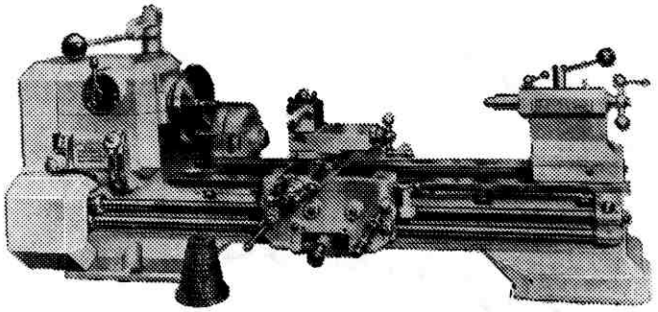

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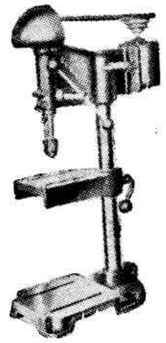

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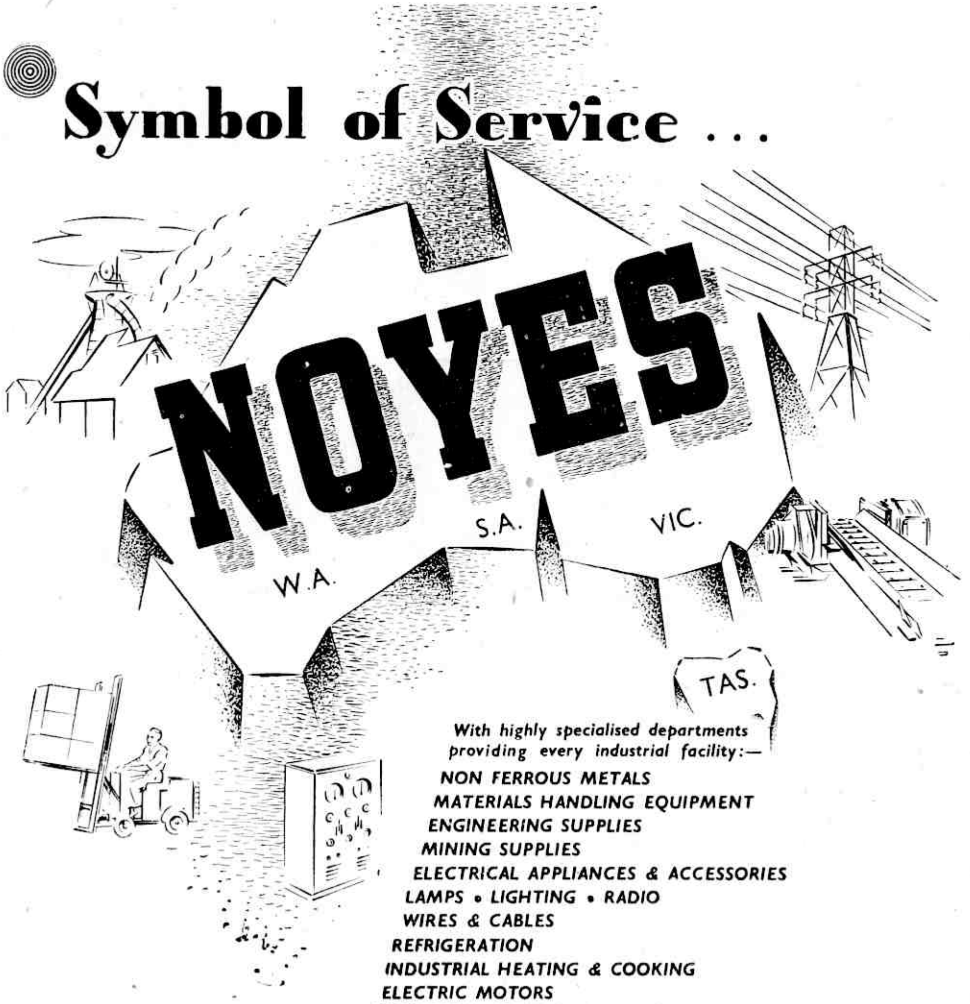
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Adelaide, South Australia.

AN INVESTIGATION ON SUPPORTS FOR LARGE DIAMETER PIPE LINES

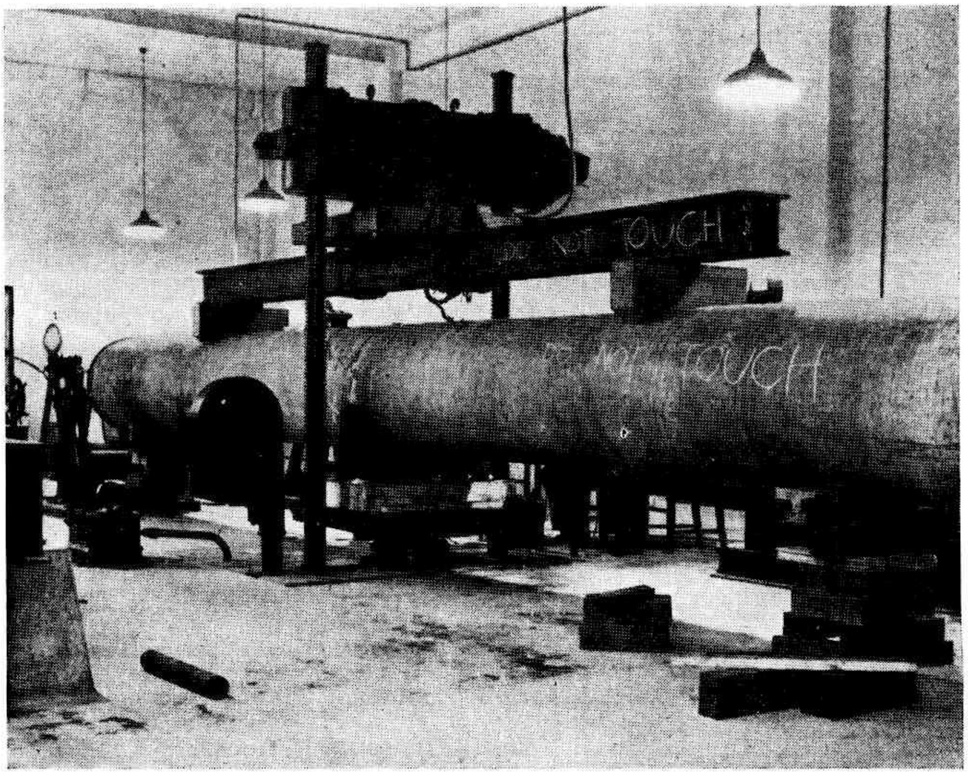
By J. E. NITSCHKE, B.E. (Hons.)

TESTS were recently carried out by Messrs. D. Causby and J. E. Nitschke, of the E. & W.S. Dept., in the Chapman Testing Laboratory of the Adelaide University, the object of which was to develop a suitable support for the Mannum-Adelaide Pipe Line. This pipe line will be laid as an above-ground expansion joint type of main, varying in size from 58 to 42 inches internal diameter.

This type of main is anchored at intervals (in this case not exceeding 660 ft.) with expansion joints between anchors, thus eliminating temperature stresses in the pipe line. For large diameter mains, expansion joint construction is generally cheaper than rigid construction as previously used for the 30-inch Morgan-Whyalla Pipe Line, where anchors and thrust blocks are required to take full temperature loads. These temperature loads would be in the order of 600 tons for a rigid 58-inch main, and anchors and thrust blocks would become excessively large structures.

For the chosen expansion type main, the supports must allow a maximum longitudinal movement of plus-minus 1.3 inches corresponding to a temperature variation of plus-minus 50° F. as anticipated under pipe empty conditions, but still restrain the pipe laterally. Both vertical and horizontal bends will be allowed between anchors, the maximum angular deflection being $3\frac{1}{2}$° for 30 feet pipe lengths. This angle is limited by both the proposed ball and socket pipe joint and the stability of the main. A minimum spacing of 30 feet between supports was desired, the maximum loading per support being approximately twice the weight of 30 feet of full pipe, comprising the dead load of the pipe and hydrostatic forces due to a maximum bend of $3\frac{1}{2}$°.

Large diameter mild steel pipes are very strong as beams, but subject to high intensity localised stresses around supports due to bending of the thin plate section. An examination of published reports of tests carried out show that stress concentration around the edge of rigid saddle supports would be excessive for the Mannum-Adelaide Pipe Line under the above conditions of loading. Reference may be may to Roark's Rigid Saddle formula—see "Formulas for Stress and Strain," p. 272; also "Tests on Cylindrical Shells," reported in Illinois Bulletin No. 331.



TESTING ARRANGEMENT SHOWING RIGID SADDLE IN POSITION

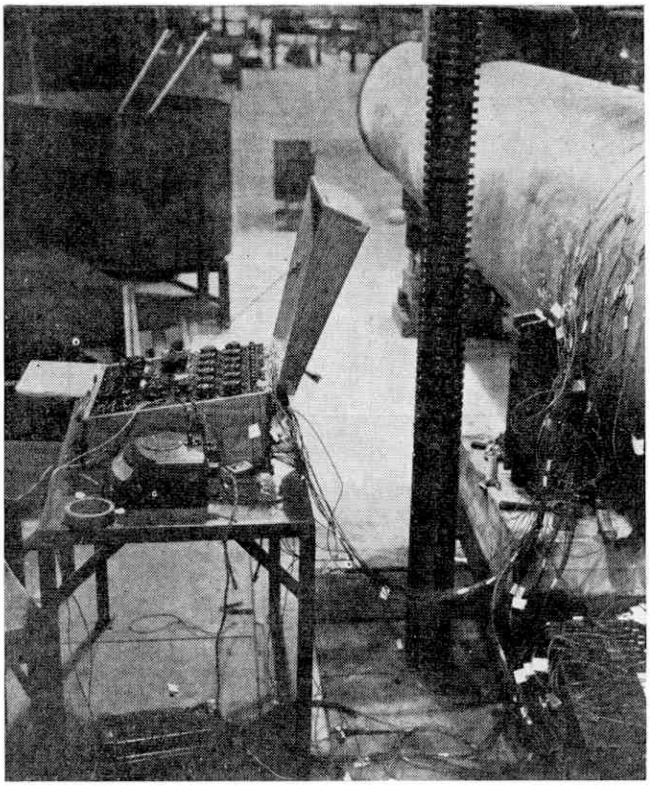
Ring girder supports are an alternative form of support which received careful consideration, this type of support practically eliminating secondary stresses in the pipe. Ring girders were used to support the 84-inch Warragamba main in N.S.W., and a local example may be seen along the Port Noarlunga road, where the 48-inch Happy Valley water main crosses the River Sturt, the span being 75 feet. It was concluded, however, that this type of support would be uneconomical for the Mannum-Adelaide Pipe Line, where topography would frequently limit spans to 30 feet, and will only be used in special cases where long spans are required, such as at creek and overhead road crossings. Structurally, 150 feet spans may be used with this main supported on suitable ring girders, but construction difficulties will probably limit the maximum spans to 90 feet.

The type of support finally selected for testing was a flexible form of saddle similar to that developed by the Tasmanian Hydro-Electric Commission. It was thought that a flexible saddle would considerably reduce the high stress concentration associated with rigid saddle supports, and would simplify construction procedure.

The problem does not lend itself to a theoretical solution, and no theoretical approach is given here. A pipe large enough to give a good estimate of the stresses expected in the 58-42 inch pipes was used in the tests. Much of the equipment used for the tests was loaned by the Civil Engineering Department of the Adelaide University, the staff of this department being very helpful. The results of previously published tests were used as a guide in conducting the tests described on the following pages.

Two flexible saddles of approximately 180° and 150° angle of contact were fabricated for testing. In addition, a rigid saddle was constructed so that a comparison of supporting stresses could be made: A 30-feet length of 30 inch x $\frac{1}{4}$ inch mild steel concrete lined pipe as used in the construction of the Morgan-Whyalla Pipe Line was used for the tests. Electrical resistance strain gauges were used to measure strains around the saddle support, these being initially placed where previous tests had shown maximum stresses to occur. Approximately 100 gauges were finally placed on the pipe externally around the edge of the saddle and internally at critical points, the concrete pipe lining being chipped away for this purpose. At critical points of maximum curvature, gauges were finally placed at approximately 1-inch centre lines, twelve gauges being wired to the resistance measuring bridge at one time.

The pipe was first loaded by filling with water using a central saddle support, but this proved cumbersome and not very satisfactory, as it was found difficult to effectively waterproof the strain gauges on the inside of the pipe. Later, the pipe was loaded in the 100-ton Avery hydraulic testing machine, as shown in the accompanying photograph. The saddle rested centrally on the bottom of the testing machine, and loading was through two wooden saddles placed 16 feet apart on the top of the pipe and two 10-in. x 6-in. R.S.J.'s bearing against the top platen of the testing machine. The two loading points 8 feet either side of the saddle were thought to be sufficiently removed from the saddle support to have a negligible effect on the stress distribution around the saddle. Maximum loads of 10 tons plus a zero load of approximately 2 tons due to the weight of the empty pipe were used with the flexible saddles. This was increased to 15 tons in the case of the rigid saddle test. Gauges on the inside of the pipe under the rigid part of the flexible saddles gave stresses non linear with load, due to this part of the saddle not accurately fitting the pipe, and importance was not attached to high isolated stresses in this region. Some trouble was also experienced due to the rigid saddle not accurately fitting the pipe, as the pipe was considerably out of round. This saddle was made $3\frac{3}{4}$ inches wide with 150° angle of contact, and it was found very difficult to make this conform accurately to the shape of the pipe.



WIRING OF STRAIN GAUGES TO RESISTANCE MEASURING BRIDGE. DUMMY GAUGES MAY BE SEEN IN THE LOWER RIGHT-HAND CORNER OF THE PHOTOGRAPH.

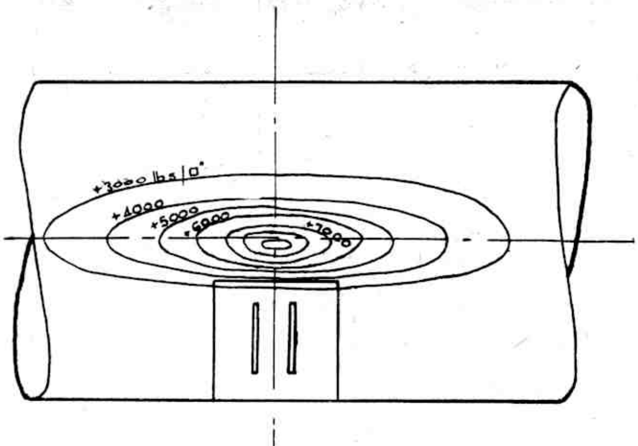


DIAGRAM SHOWING CONCENTRATION OF
CIRCUMFERENTIAL STRESS ABOVE SADDLE.
ON OUTSIDE OF PIPE.
150° Flexible Saddle shown
Load | 10 Tons
Ext. Pipe Dia. | 31½" Thickness ·267"

FIGURE 1

In this case an additional 5-ton zero load was used.

Gauges were also placed on the concrete pipe lining to determine if this added to the strength of the pipe against local deformations. Readings were very irregular and indicated that the concrete lining contributes very little to the plate strength.

Measured saddle stresses were corrected for stresses due to beam action of the pipe, these bending stresses being close to the calculated values at the top of the pipe when the concrete lining was neglected. Measured bending stresses on the bottom of the pipe were greatly modified by stresses due to the saddle.

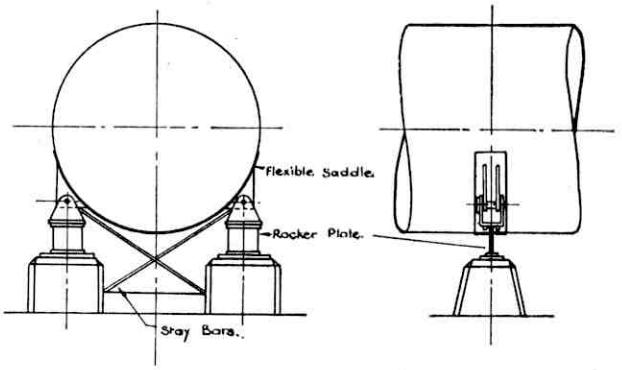
Maximum measured stresses occurred just above the top of the saddle in all cases, these being due to circumferential bending of the pipe shell. Fig. 1 shows concentration of circumferential stress on the outside of the pipe above the smaller flexible saddle. Corresponding stresses on the inside of the pipe were of opposite sign and greater in magnitude, showing that the circumferential bending was associated with a circumferential compression. This greater compressive stress on the inside of the pipe is not serious when combined with a uniform tensile stress due to water pressure in the pipe, the smaller outside tension giving the worst combined stress.

Longitudinal stresses appreciably less than the maximum circumferential stress were found to exist around the edge of the saddle, and the longitudinal stress associated with the maximum circumferential stress was not appreciable.

Maximum measured stresses were less than that given by Roark's saddle formula mentioned previously, being 80% of this for the rigid saddle tested and averaging about 65% in the case of the two flexible saddles. The maximum measured circumferential tensions were correspondingly less, being 62% and 49% respectively of Roark's stress. The reduced rigid saddle stress may have been due to the saddle being wider than usually used, and also some flexibility due to the saddle not fitting accurately along the edge. These figures were used as a basis for estimating the maximum saddle stress likely to occur in the larger Mannum-Adelaide pipes. The position of the supporting pin was varied in additional tests on the flexible saddles to try and further reduce plate bending. Moving the pin further out from the centre of the pipe increased the stresses above the edge of the saddle, whilst moving the pin further in decreased these stresses, but only at the expense of increased stress below the rigid part of the saddle. The pin was left in its initial position, this point being such that the line of vertical reaction through the pin, a radial line through the centre of the rigid part of the saddle, and the tangential strap tension, have a common point of intersection.

The maximum combined stress due to saddle action, water pressure and beam action was limited to the yield point of the material. The smaller flexible saddle was chosen as a satisfactory support for a maximum size pipe of 58-in. diameter, using 30-ft. spans on bends and 45-ft. spans on straight sections.

The required longitudinal movement is effected by mounting the saddles on rocker plates, and lateral stability assured by incorporating stay bars into the rocker assembly as shown in Figure 2. On horizontal bends it is necessary to use wider rocker plates than normal and super-elevate the rocker assembly to obtain lateral stability.



PROPOSED ROCKER ASSEMBLY FOR 58 PIPE LINE,

FIGURE 2.

CIVIL ENGINEERING POST-GRADUTE WORK

By J. D. C. CRISP, B.E. (Hons.)

SYNOPSIS.—Being a review of extra-curriculum investigational work conducted in the Department of Civil Engineering over the past few years; also with reference to present and intended projects.

IT has been stated, often, and with emphasis, by eminent educationists in all the English-speaking countries, that the true worth of a University in terms of the ultimate good to the community is best reckoned from its ability to undertake extra-curricula research—which must inherently be of a more fundamental nature.

That this general principle is true will readily find agreement with us, and that its fulfilment is desirable cannot reasonably be contested. A hasty condemnation when viewing the Faculties of Engineering in Australian Universities in the light of this ideal is perhaps a result of an unfavorable comparison with English institutions. But in defence of our home organisations it is suggested that the conditions are not entirely similar—that the demands of a large, sparsely populated, and as yet under-developed country (as is Australia) have produced the need for a different type of engineering graduate—a man perhaps more versatile and less specialised, who relies on foreign importation of "new fundamentals."

It has long been realised in this country, and vividly shown by the swift world processes of the last decade, that such an attitude is not entirely satisfactory. And so it is that Australia, through various national bodies, moves on to a period in which research has its place beside other development—and that, a more stable place.

With the advent of the Universities Commission and Commonwealth Research Grants, a parallel quickening in the research field has been noticed in university studies. The introduction of higher degrees has offered further incentive to the qualified man. An increasing ratio of lecturing staff to students is designed to promote more profitable extra-curriculum work, by the relief afforded to the individual lecturer.

The following account of such work in the Civil Engineering Department should indicate the extent to which circumstances have allowed the attainment of continuous, organised research. Under staff supervision, projects have been undertaken variously by undergraduates holding research grants, honours students (as requirement for their course), graduates proceeding to higher degrees, and members of the lecturing staff on a part-time ("spare-time") basis.

Here follows a brief summary, roughly in chronological order, of the various investigations of interest.

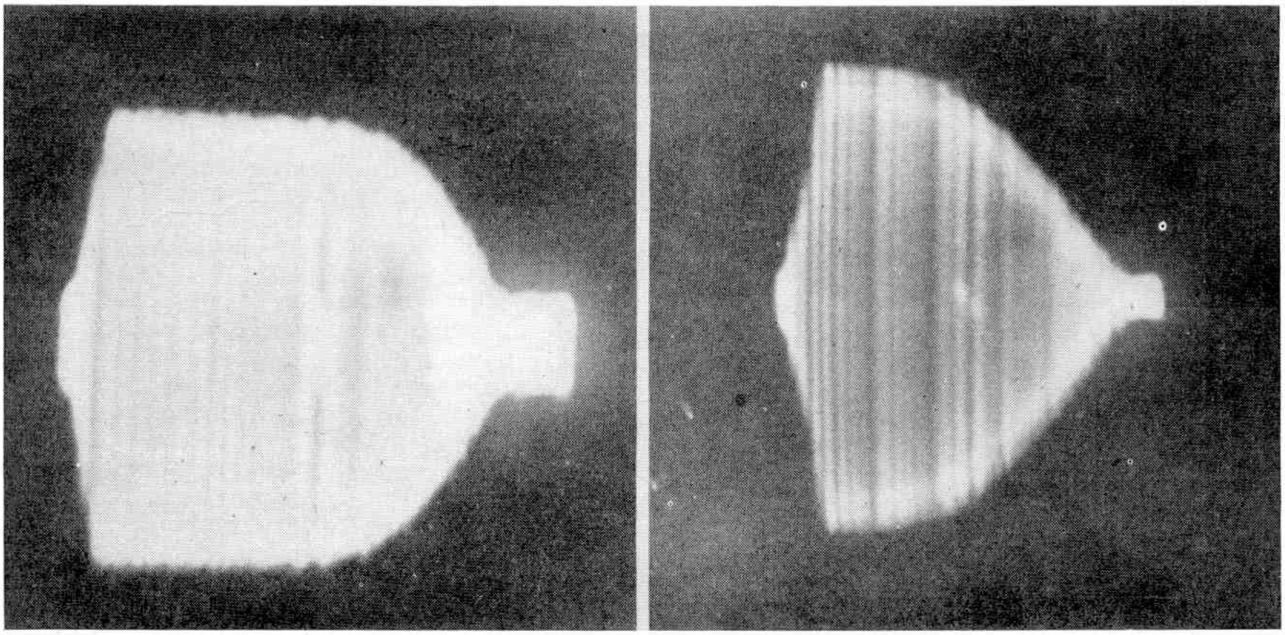


FIGURE 1. OSCILLOSCOPE TRACE OF LOAD-TIME CHARACTERISTIC. One cycle shown for frequencies 10 and 22 per minute. Half-ordinate proportional to applied load.

FATIGUE IN BOND

Early in 1946 the design of a 120 kip universal testing machine was commenced as the first stage in a study of fatigue in bond in reinforced concrete. Such a work was necessary to bring to completion a project which had been under notice some years previously, the object of which was the determination of factors affecting bond between steel reinforcing and concrete. The fatigue aspect had been a much neglected subject in world literature, and the little information available was outdated by the improved properties of the modern Portland cements—it was further rendered confusing by the great diversity of test conditions and in many cases contradictory results reported by the early workers.

Professor Lea (1940) reported a fatigue limit in bond for a three to one mortar which was of the order of 0.60 of the static bond strength. His load frequency was 2,000 cycles per minute. More recent work conducted in Paris (1945) indicates a coefficient of 0.69 for concrete, obtained from "push-out" tests with a load frequency of 500 cycles per minute—this work, by La Camus, also mentions a similar figure by Wohler of 0.75. It was the purpose of the work undertaken in the Civil Engineering Department to determine this fatigue coefficient for a range of concrete types and to study also the factors which influence it.

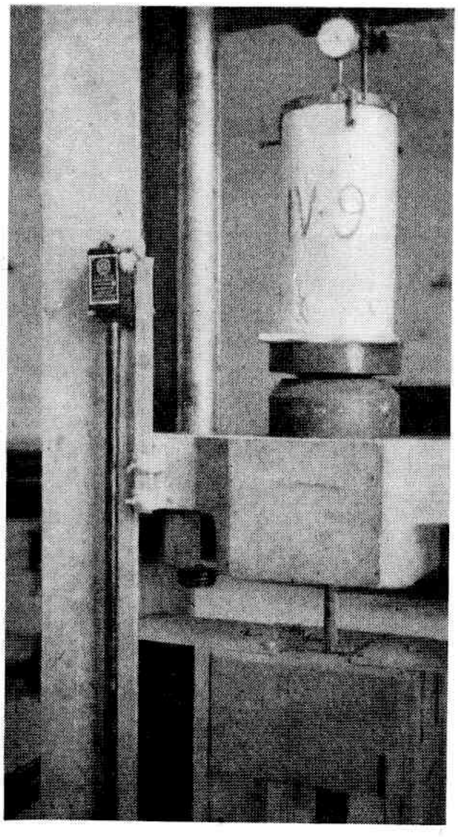


FIGURE 2. PULL-OUT TEST PIECE UNDER TEST IN 60 KIP FATIGUE MACHINE. Load recorder and fatigue attachment not shown.

The first step, as mentioned, was the design, fabrication, assembly and calibration of a suitable testing machine. The machine (hydraulic) was intended for general use and adapted for fatigue loading (up to 60 kips) by the addition of a cam-actuated release valve which brought the load to a maximum preset value (tension) and released it to zero each cycle. Load setting was done under static conditions by adjusting the position of a jockey weight on a pivoted lever, and the load-time characteristic of the machine was controlled within limits by use of varied-contour cams. Frequency of load repetition was 22 cycles per minute for almost all tests. Large loads required one of two lower frequencies—adjustable by a pulley and belt ratio change. Figure 1 shows the load-cycle obtained at two different frequencies (10 and 22 per minute), from a steel tensile test piece on which were mounted electrical resistance strain gauges relaying to an oscilloscope.

The specimens, of the "pull-out" type, consisted of $\frac{3}{4}$ inch diameter structural steel reinforcing bars, 32 inches long, embedded centrally and axially in concrete cylinders 6 inches diameter by 12 inches high. Casting was in a vertical position and curing at 56°F. under water, until testing. The test specimen was inverted in the testing machine and the protruding steel bar held in the lower tension grips of the platen. A 1/10,000-th dial gauge measured movement (or "end slip") of the upper end of the bar relative to the top of the embedding concrete.

"Initial slip" was defined as a movement at this point of more than 0.2/10,000 inches. Loading was at all times tensile, and applied through a spherical head and $\frac{3}{8}$ inch plywood packing. The maximum load used, 16 kips, corresponds to a bond stress of 570 lb. per square inch. Figure 2 illustrates a specimen under test.

Some 113 specimens, including compression control pieces were tested both statically and dynamically, commencing about September of 1947. Six batches of specimens, of about 19 per batch, were machine-mixed, two different types of local Portland cement being used as they became available. Five different mixes were designed, and in all the material consisted of $\frac{3}{4}$, $\frac{3}{8}$, $\frac{1}{8}$ inch crushed stone and Noarlunga sand. Optimum sand percentage was used (46 per cent.) and slumps of one to two inches obtained. The water-cement ratio was maintained at 0.50 or 0.60. All the mixes used were of high consistency (low slump) and high compressive strength. This was a consequence of the attempt to produce uniform test specimens. Typical values of 30-day compressive tests, for the above concretes, were 4,200 lb. per square inch at w/c = 0.50, and 2,800 lb. per square inch at w/c = 0.60. Testing was often at ages greater than 30 days, and for large numbers of repetitions, a single test might occupy several weeks. An age-correction factor was applied to the results of all such tests and an equivalent result found at 30 days. Figure 3 is a plot of the final endurance limit curves obtained. No tests were conducted for repetitions greater in number than one half of a million.

The following points emerged from this investigation. Firstly, for the concrete mixes used, the endurance limit lies between 140 and 250 lb. per square inch applied bond stress—the actual figure is affected, within this range, by w/c ratio, slump (i.e., percentage water), and the type of cement. The value of the endurance limit is governed also by the grease-condition of the embedded bar.

If P is defined as the ratio fatigue load/initial slip load, then the endurance limit coefficient P lies within the range 0.65 to 0.70. For a bar greased (even slightly) this figure becomes 0.90 plus or minus. If P' is defined as the ratio fatigue load/ultimate static bond strength, then the coefficient P', for all types of concretes used, irrespective of bar surface condition, lies in the range 0.32 to 0.35.

The previous figures 0.65 to 0.70 compare very favorably with the coefficient recorded by La Camus, when it is remembered that his "static bond strength" is defined as that load (or stress) at which end slip first occurs, that is, the initial slip load as defined in our work. Further work with concretes of lower compressive strength and over larger repetitions, together with correlation tests to enable application of these factors to conditions of mixing, casting and curing in the field are necessary before one can assign a value within the range of 0.65 to 0.70. It becomes apparent, also, that care must be exercised in interpretation of the meaning of "static bond strength" as opposed to "ultimate static bond strength."

When considering the great diversity of testing conditions as regards specimen type (pullout, pushout, beam), load frequency (22 to 2,000), load cycle (repeated and alternating), concrete type ($\frac{3}{4}$ inch to mortar), as well as the usual difficulties of uniformity and homogeneity associated with concrete, it is remarkable that the values obtained by the various workers should lie within so close a range.

WIRE RESISTANCE STRAIN GAUGES

The use of electric resistance wire strain gauges for the determination of the dynamic load characteristic of the fatigue testing machine was mentioned above. The introduction of this method of strain measurement has greatly widened the horizons of the experimental stress analyst. The technique of the application and use of strain gauges was therefore of considerable interest, and the Civil Engineering Department has made the manufacture of electric wire strain gauges another of its projects. Briefly, the principle of the method is this. A small grid of fine wire is bonded intimately to the surface of a component of a machine or structure which is to be stressed. Surface strain at this point in the direction of the length of the wire strands, due to the Poisson ratio effect, causes a change in sectional area (diminution if a tensile strain, increase if compressive) of the wire, and therefore a corresponding (linear) change in electric resistance. This change of resistance can be successfully and accurately measured by causing the gauge to be in one leg of a sensitive Wheatstone's bridge circuit. The out-of-balance current (due to strain) or the galvanometer deflection is a measure of the resistance change and therefore of a weighted mean surface-strain over the area covered by the gauge. Temperature effects can be nullified by use of a "dummy" gauge, a replica of the "active" gauge, in the opposite leg of the bridge circuit. Special circuits are made up for this work, and in the Chapman Testing Laboratory a twelve-channel strain meter unit is used. Provided the "gauge-factor" for a particular batch of gauges is known, the galvanometer can be directly calibrated to read strain (inches/inch). Gauge factor is defined as the ratio,

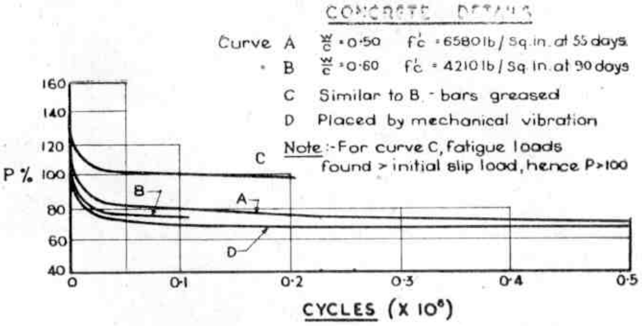


FIGURE 3. ENDURANCE LIMIT CURVES FOR BOND.
P per cent. is the ratio fatigue load/initial slip load.

$$K = \frac{dR}{R} \Big/ \frac{dL}{L}$$

where dL is the increment of elongation L

$$(\text{i.e., } \frac{dL}{L} = \text{strain})$$

and dR is the change in resistance R of the bridge circuit.

For resistance wire gauges K has the value of about two, and is independent of the physical geometry of the gauge, depending only on the resistivity properties of the wire used. Commercial imported gauges are made from copper-nickel or copper-manganese wire, usually of diameter about 0.001 inch and range in gauge length from $\frac{1}{4}$ inch to 1 inch, the number of strands of the grid varying from six to about twice that number. The gauges, once applied to a surface, usually by a nitro-cellulose base adhesive, are not recoverable for further use. High cost and scarcity of the imported gauges suggested self-manufacture, so that a winding jig was made up. With the aid of this jig, the grid of six strands of "Advance" wire (a copper-nickel alloy, of 0.001 inch diameter and 264.8 ohms/foot), of $\frac{7}{8}$ inch gauge length, was readily wound. It proved a difficult task, requiring some skill and practice to perfect the attachment of the leads (flattened Eureka wire was used) by spot welding with a shaped electrode fitted to an "electric pencil"; the resultant grid with leads was then incorporated between two sheets of fine rice paper and cut to shape. The stage was reached where the output of these gauges rose to five per hour under good conditions, with an 80 per cent. success rate—by which is meant complete gauges registering within one ohm of the mean gauge resistance for a batch (usually about 118 ohm) eight times out of ten.

It remained to determine the gauge factor before use could be made of them. Usually, a calibrating beam is employed, in which a known strain is applied to one or two gauges from a batch of, say, 10 or 20 and resistance changes measured by the strain meter bridge.

A pure moment is applied to the beam by a symmetrical four-point loading and deflection measurements by 1/1,000 inch dial gauge enable calculation of extreme fibre strain. Increased accuracy and greater convenience in calibration was aimed at in the direct micrometer-reading cantilever strain gauge calibrating beam designed and built in the University Workshops. It consists essentially of a 15-inch tapered "triangular" cantilever of rectangular section, which under a concentrated load at its end deflects into the arc of a circle—so producing constant surface strain along its length. The end deflection is measured by a micrometer screw (without backlash) having a range of plus or minus 1.250 inch, with smallest reading of 1/1,000 inch—readings of 1/10,000 inch can readily be estimated. It has proved very satisfactory, giving consistently reliable results, and in ease of operation much to be preferred over the standard calibrating beam.

The electric resistance wire strain gauge has now become a standard apparatus for strain measurement in the Chapman Laboratory. Studies for its use under water are now in progress. A second Wheatstone's bridge, suitable for research work rather than routine testing, is on order.

PHOTO-ELASTICITY

Within the last eighteen months another important tool has been added to the kit of the research elastician and stress analyst in the setting up of the photo-elastic section of the Research Laboratory. Photo-elasticity is a powerful and accurate means of stress determination in a fairly large class of problems (plane and three-dimensional), and yields information often not otherwise obtainable. It can be rapid and possesses strong visual appeal—see Fig. 4. The dark fringes are lines of constant principal stress difference p—q; p and q represent the major and minor principal stresses respectively. At a free boundary, the "q" stress must vanish, so that then each fringe, with its appropriate stress parameter, represents the actual stress (a tangential one). Provided the fringe stress parameter is known or the stress-optic coefficient as it is called, a direct means of determining boundary stresses is available. Transparent stress-optic sensitive materials are used in sheet form, from which a model is machined. When loaded and placed in polarised light, the change in optical properties along the principal axes of stress of the model due to the stressed condition of the material are a measure of the stresses induced by the particular loading:—the stress-optic law is linear and the constant readily found by calibration with a tensile specimen, where the state of stress (uniform) is readily calculable.

The polariscope in use has a 3 inch diameter field and employs polaroid discs for polariser and analyser, with mica-between-glass quarter wave plates. Projection of the stress pattern (as in Figure 4) is on to a ground-glass tracing screen, or to a negative of a half-plate camera. Stress pattern quality (measured in terms of the number of clear fringes per inch for a given thickness of model material) or attainable accuracy is very dependent on the design of the optical system of a polariscope, and in this regard the light source is important. Two sources are provided, one a 125-watt mercury lamp with filters, which furnishes monochromatic light (of wavelength 5350 A.U.); and a 250-watt projection light (white light). In the former case fringe quality or definition can be improved by drastic "stopping down" of the camera lens—this involves, simply, longer exposure times. For the white light, which produces a colored pattern, somewhat expensive to photograph, stopping down is not permitted and modification of the light source is resorted to. The use of a "point-o-lite" lamp, of 500 candlepower, which produces a very small, intense source, has proved successful. Various other modifications and adjustments of the optical system have been necessary to render the polariscope suitable and more convenient for research work.

Until recently, most work has been in the development of technique and application of the gelatin method in photo-elasticity. The usual photo-elastic materials, which of course must exhibit the "temporary" stress-optic effect, are such as cellulose nitrate (celluloid or xylonite), catalin 800, clear bakelite, columbia resin (C.R.–39) and others. They have varying degrees of optical sensitivity, varying advantages and particular uses. Thus bakelite (very costly) is reserved for accurate work; catalin (readily machined) is employed where models are complex in shape; celluloid is a good basic material, etc. Gelatin, however, is characterised by its extremely high stress-optic sensitivity, being approximately one thousand times as great as that of some of the above materials—in fact, it produces a stress pattern with its own weight as the sole loading. This property has made it suitable for the solution of problems in which the body force (e.g. weight) is the only or major loading. A case in point was that of the elastic flexible bulkhead retaining an elastic fill. The determination of stress distributions on the bulkhead faces is not possible mathematically, and a photo-elastic study afforded a means of doing this. Some four models under both body and external loadings enabled a variety of conditions to be tackled.

The gelatin technique is not simple and involves several complications, not least amongst which is the need to support the gelatin slab laterally, and that without friction. A 20 per cent. gelatin solution (with 20 per cent. glycerin) is poured hot (40°C.) into a glass-sided mould shaped to produce the $1\frac{1}{4}$ inch thick model. It is refrigerated quickly at 4°C. and cured at 10°C. for 24 hours, when the mould is stripped, lubricated and reassembled ready for test. Gelatin in this form is extremely temperature-sensitive and for accuracy temperature control to within one half of a degree (C.) is desirable. To this end, a temperature conditioned below-ground room is in process of preparation, and the polariscope (or a second one with large-field designed specifically for gelatin work) will be transferred there.

In photo-elasticity, present and future work will take the form of an investigation into the possibilities of the extension of the method to cases where plastic failure occurs. This involves a preliminary study of available photo-elastic materials with a view to discovery of one exhibiting a "plastic" stress-strain characteristic —similar to mild steel. For this purpose, the measurement of large strains (up to 30 per cent.) is desired, and an optical method of mechanical interferometry for strain measurement in the plastic range is being developed. Accuracy will be required both in the elastic range (strain less than about 2 per cent.) and the ensuing "plastic" range. The method is intended to achieve this.

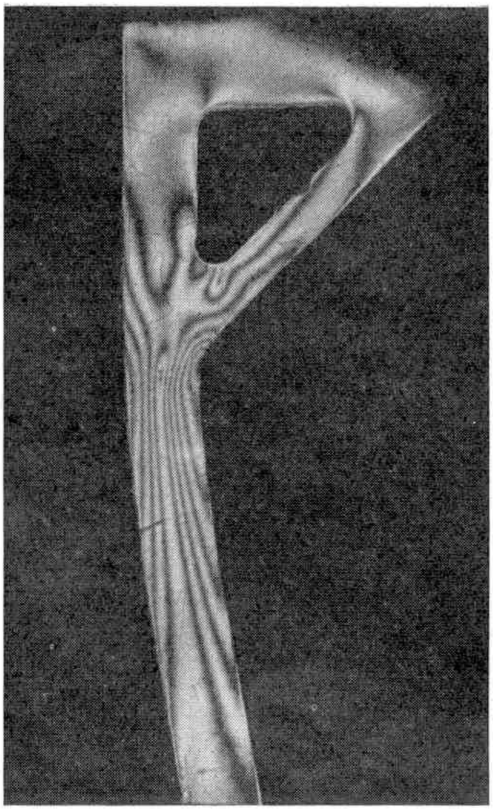


FIGURE 4. STRESS PATTERN FOR COLUMN OF PORTAL FRAME—Magnification x 3/2. Xynolite (celluloid) model; horizontal load = 17 lb. applied at top; model fringe value = 220 lb. per square inch; monochromatic light wave length 5300 A.U.

Stress patterns as obtained from the polariscope (see Figure 4) indicate at any point in a body the (p — q) value. The pattern is not therefore a complete solution for an interior point. Many methods exist for the complete separation of the principal stress p and q, most of them experimental (requiring further work), and most of them involving the determination of the quantity (p + q) at the point under consideration. Some of their disadvantages include inaccuracy, costliness, tediousness—all possess some of these to a degree. If successful, the above-mentioned method of (optical) strain measurement, in the elastic range, provides a happy compromise for (p + q) determination. For the quantity (p + q) can be expressed in a simple mathematical form, in terms of (p — q), other data obtainable from the polariscope, and the strain in a given direction OX. It is intended to follow this line, also, to test its possibilities.

Photo-elasticity has much to commend it, and is capable of very wide application. It is limited, of course, to problems in elasticity.

PREDICTION OF CONCRETE STRENGTHS

To return to the realm of concrete: it is of interest to note a few results obtained from an investigation into the prediction of 28-day strengths from earlier tests (three and seven day tests), in relation to local aggregates, sands and cements. The method is based on a paper by J. J. Creskoff (see Bibliography). A simple basic formula is used and its coefficients are found by application of the method of least squares to data obtained from test results (3, 7, and 28 days). Thus $fe = Kd$, where fe = predicted 28 day strength; K and d are coefficients, obtained from the three and seven day tests and some preliminary 28 day tests. Once K and d are determined from test data, for a particular mix or a particular set of aggregates, fe is readily found. A "particular mix" implies only constant mix proportions; water-cement ratio and slump may vary. The coefficient K is a function of three, seven and 28 day tests; d is a function only of the three to seven day tests.

The following local materials were used, proportioned as follows: $\frac{3}{4}$, $\frac{3}{8}$, $\frac{1}{4}$ inch Noarlunga sand, cement, in the ratios 35: 15: 10: 25: 15. Some 144 cylinders (six inch diameter by 12 inches) were cast in six batches, and the following variables used: water-cement ratio (three cases 0.63, 0.67, 0.70); cement (ordinary Portland A type, ordinary Portland B type, high early strength); mixing (hand and machine); placing (hand tamping and vibrating); curing (fog room for clinders used to calculate K and d, in water, indoor air, outdoor air, wet bagged, in wet sand). Standard tests were made on every bag of cement used.

For the two ordinary Portland cements (A and B), predictions within 10 per cent. of the observed 28 day strengths were obtained. In the determination of the constants K and d, the use of ten specimens will allow a probable error of 8.8 per cent—this is reduced only to 8 per cent. by the use of an infinite number of specimens, as is shown by the Theory of Probability. It is intended for future work to gain closer control by installation of temperature control in the fog room for curing, and the sealing during casting of the steel moulds by rubber caps. For convenience in handling and mixing, a smaller (3 inch diameter by 6 inch) test cylinder will be used.

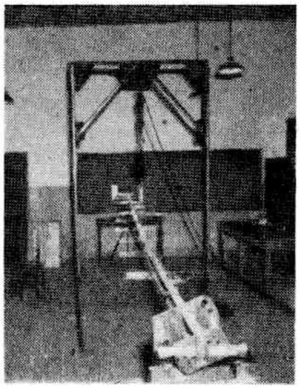


FIG. 5. LATERAL STABILITY OF I-BEAM, TEST SET-UP.

STABILITY OF ROLLED SECTIONS

A fifth project to be mentioned here concerns the stability of beams and rolled sections. It is well known in reference to long columns that it is the buckling load (for example, Euler's critical buckling load) which is of importance; and so with certain beams of large span, the lateral buckling load may at times be critical. The theory of elastic stability shows that the critical buckling load or the load at which failure by lateral instability occurs may be written in the form

$$P = \frac{m\ (B_1 C)^{1/2}}{L^2}$$

wherein B1 is the "minor flexural rigidity" of the beam section and is thus a function of the beam dimensions and the tension modulus E; C is the "torsional rigidity" of the beam section and is similarly a function of the beam dimensions and the shear modulus G; L is the beam span.

The quantities E and G must be determined experimentally. Calculation of the constant "m" may be made from theory in many cases, and its value is dependent on the type of loading applied, whether concentrated, uniform or pure moment; the condition of end fixity, whether built in, simply supported or cantilevered; and also on the section shape, whether rectangular, rolled channel or I-beam, etc. In this latter case, "m" becomes a function of a ratio $(L/a)^2$, where a is a quantity involving D, the flexural rigidity of one flange of the I-beam in the plane of the flange. For simple loadings, such as central concentrated loads, evaluations have been made for "m." It was the purpose of the investigation to verify experimentally some of these constants and to establish other values for other non-central load conditions. At the same time a measurement of the torsional deflection axis was made to compare with the theoretical curve.

Figure 5 illustrates the set-up in the Chapman Laboratory, in which a 4 x $1\frac{3}{4}$ inch nominal I-section, 30 ft. span beam is under a single centroidal load applied close to the near support. The two supports were designed to produce complete freedom of rotation in two normal planes of the beam ends, as indicated. Deflection measurement was accomplished by the use of ten equally spaced transparent targets scribed on to perspex, and viewed on the two sides of the beam by two microptic theodolites. Focus was obtained on each target in turn for a given load condition, both vertical and horizontal angle measurements being made. The analysis of results is not yet complete.

A bibliography is added for reference for the interested reader.

The author wishes to express his thanks to all the people who have contributed material which enabled this report, and in particular to Professor Robin for his permission to allow publication.

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THE PREDICTION AND MEASUREMENT OF OCEAN WAVES

By P. BROKENSHA, B.E.

INTRODUCTION

THE prediction of wave characteristics for the design of harbor works has always been a rather uncertain procedure. The many amphibious landings made by the Allies in the recent war demanded that a method of forecasting sea and surf conditions at landing beaches be devised. As a result the problem was, and still is, being thoroughly investigated. A comprehensive account of the theory of forecasting wind waves and swell is given by Sverdrup and Munk[1].

In this article a brief sketch of some of the work being done on wave prediction and measurement is given, as well as an outline of the way in which the wave investigation of a port could be undertaken.

THE FORMATION OF WAVES

It is common knowledge that waves are formed by the transference of energy from wind to waves. From the work of Munk[2] and others it is probable that a sea surface would behave somewhat as follows under the influence of a steady wind of gradually increasing velocity.

Until the wind speed reaches about 23 cms. per second ($\frac{1}{2}$ m.p.h.), the surface of the water will be unruffled. Between 23 cms. per second and 110 cms. per second ($2\frac{1}{2}$ m.p.h.), the surface will become covered in small surface tension ripples which will die out immediately the wind drops. At 110 cms. per second small wind waves are first formed, and these may continue to grow in length and height until they reach a maximum value limited by the fetch or duration of the wind. At the critical speed of around 660 cms. per second (13 m.p.h.) the sea surface becomes turbulent and unstable wavelets, which themselves grow with increasing wind velocity, are formed. These are responsible for much of the characteristic irregularity of ocean wind waves.

H. Jeffries has given a simple yet fairly satisfactory explanation of the mechanics of the growth of waves under the action of wind. The leeward side of the crest experiences a sheltering, hence the pressure on the windward side is greater than that on the sheltered side. With waves travelling in the same direction as the wind, the water particles are moving downwards on the exposed side of the wave and upwards on the sheltered side. Hence the distribution of normal wind pressure encourages the water to move downwards where it is already moving downwards and upwards where it is already moving upwards.

THE PREDICTION OF WAVES

Sverdrup and Munk[1] have derived expressions for wave height and length in terms of fetch, wind velocity and duration. The maximum theoretical wave height and length for waves formed by winds blowing over an unlimited fetch depend upon the wind velocity and approximate to the following expressions:

where:

U = wind velocity

H = wave height

L = wave length

$$H = \frac{0.26\, U^2}{g} \quad \ldots\ldots \quad \ldots\ldots \quad 1$$

$$L = \frac{11.5\, U^2}{g} \quad \ldots\ldots \quad \ldots\ldots \quad 2$$

all in consistent units

Equation 2 was obtained by applying Sverdrup's maximum ratio for wave velocity to wind

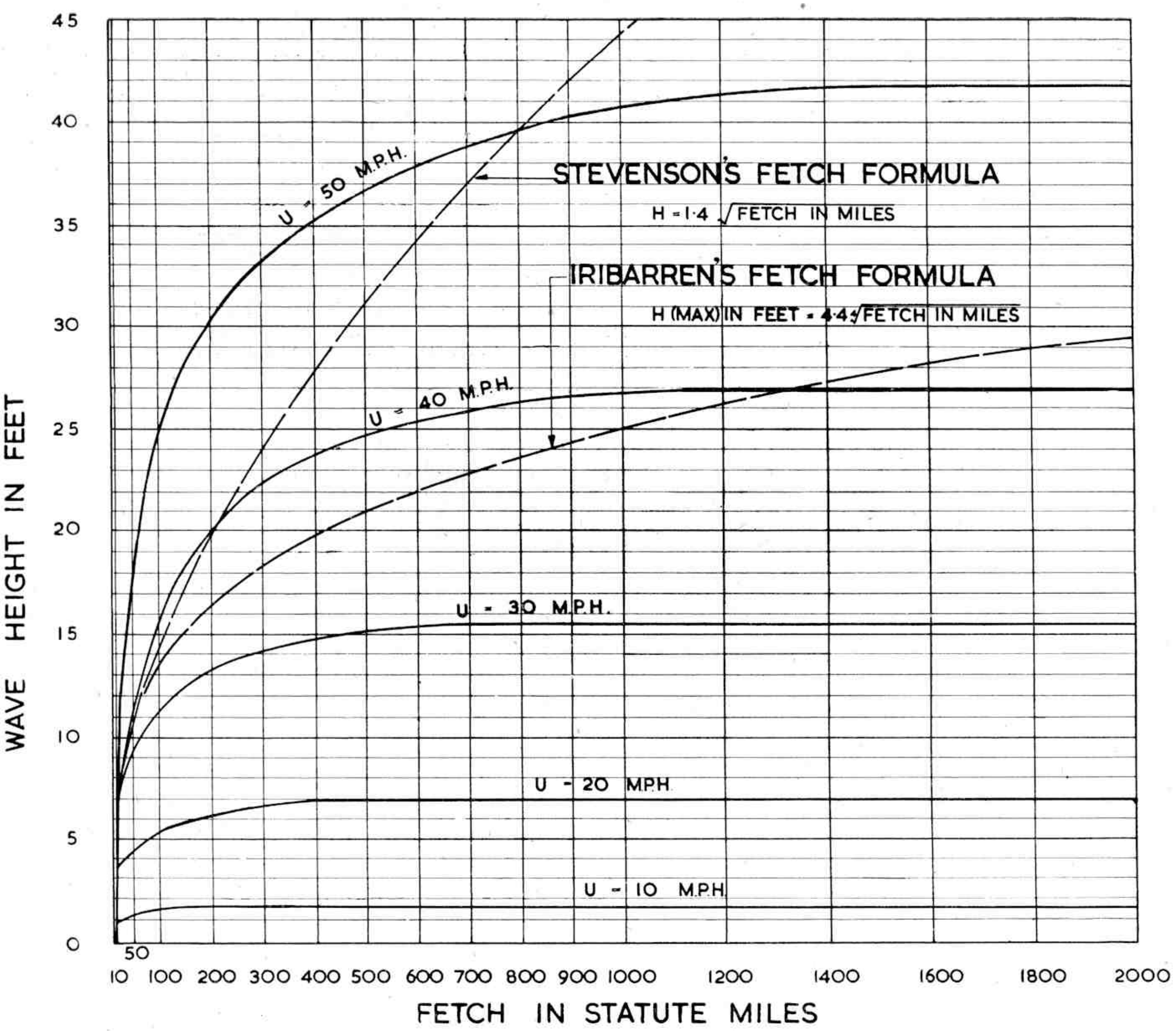


FIGURE 1. GRAPHS SHOWING THE WAVE HEIGHT IN TERMS OF THE FETCH AND WIND VELOCITY. (Adapted from Sverdrup.)

velocity of 1.35, to the classical equations connecting wave length and velocity.

Figs. 1 and 2 are curves which enable the wave height to be forecast for any condition of fetch, wind velocity and duration. These curves have been adapted from Sverdrup's graphs connecting the non dimensional parameters $\frac{gH}{U^2}$ with $\frac{gt}{U}$ and $\frac{gF}{U^2}$, where F is the fetch and t the duration.

If the maximum expected wind velocity and the fetch are known, the wave height corresponding to the conditions can be obtained from Fig. 1. From Fig. 2 another wave height may be obtained by inserting the corresponding expected duration of this wind. The smaller of these two values is considered valid, as either insufficient fetch with a theoretically unlimited wind duration or insufficient wind duration with an unlimited fetch impose a limitation on the growth of the waves.

On the fetch and wind velocity graph is also shown a line representing Iribarren's[3] fetch formula

$$H = 1.2\ (\text{Fetch})^{1/4}$$

whilst his corresponding length formula is

$$L = 31\ (\text{Fetch})^{1/3}$$

where H = wave height in metres
L = wave length in metres
Fetch is in kilometres

On the same graph Stevenson's classical fetch formula is also shown. This is

$$H = 1.5\ (\text{Fetch})^{1/2}$$

where H is in feet and fetch in nautical miles.

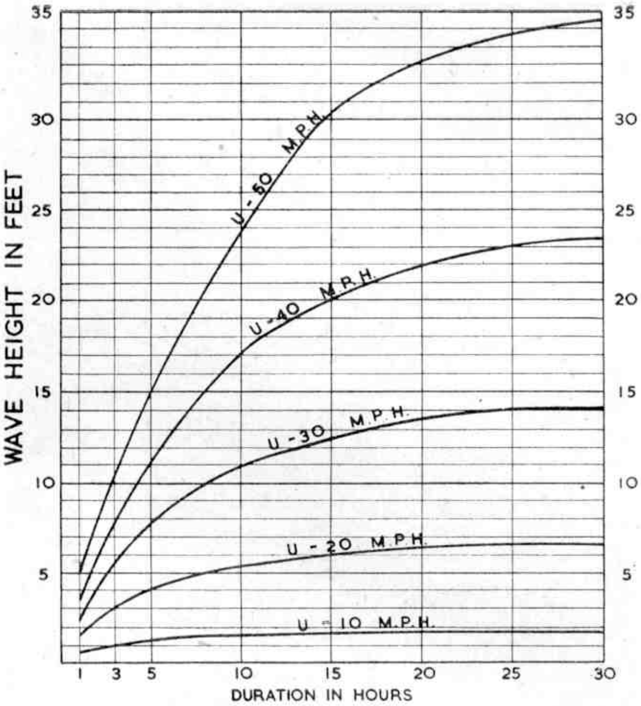
These are both empirical formula, not related to any wind conditions, but intended to apply to the greatest expected wind velocity and duration at any location.

It has been established that winds of greater than about 45 m.p.h. seldom blow over the oceans for any considerable length of time. Stevenson's formula would therefore appear to give fairly correct design heights for fetches less than about 600 or 700 miles (see Fig. 1), and is in fact generally accepted for fetches less than that. Iribarren's formula is likely to give an under-estimation of wave height for fetches less than about 2,000 miles. In his paper[3] Iribarren quotes examples of fetches of 600, 2,500 and 9,000 miles where observed wave heights agreed very closely with the heights given by his formula. Iribarren also presents a series of graphs showing wave height as a function of the wind velocity and fetch which were adapted from graphs prepared by Commander Suthons of the British Navy. Both Suthons' and Sverdrup's curves were used in the early forecasting work for the invasion of Normandy.[4] However, Sverdrup's curves proved more reliable; the many other confirmatory observations as well as their sound theoretical basis make them the more acceptable for general forecasting work. It is probable, however, that the curves have been slightly modified from later work by R. S. Arthur[5] not yet available here.

WAVES IN SHALLOW WATER

The wave heights and lengths as obtained from the above method are defined to represent the characteristics of the "significant waves," i.e., the average of the one-third highest waves, which approximates to the value a careful observer would assign to the highest waves. These are the characteristics in deep water, where the orbital motion is unaffected by the presence of the bottom. As the amplitude decreases exponentially with depth the motion will be very small at a depth of half the wave length which is arbitrarily selected as the depth when waves first start to feel the bottom. As waves move into water shallower than this there is generally, depending on the wave dimensions and the slope of the sea floor, an initial decrease in height and then a peaking up in height before the wave breaks. Breaking will occur generally when the wave reaches a depth of water between once and one and a half times the height of the breaking wave.

The variation of wave height and length for a wave advancing into shallow water may be important in the design of harbor works. The usual method of finding these is to plot wave fronts on a refraction diagram (Munk and Traylor[6]) or wave chart (Iribarren[7]). Iribarren's method is the simpler and has been extensively used in work done by the South Australian Harbors Board.



WAVE HEIGHT IN TERMS OF WIND VELOCITY

FIGURE 2. GRAPHS SHOWING THE WAVE HEIGHT IN TERMS OF THE WIND VELOCITY AND DURATION. (Adapted from Sverdrup.)

THE MEASUREMENT OF WAVE HEIGHTS

The accurate measurement of wave heights over any length of time is usually a difficult and expensive problem. There are many different methods in use; reference will be made to a few of the more important ones.

1. Photogrammetry:

This method was successfully used by Schumacher to produce accurate contours of waves from aboard the Meteor in 1925-26. Seiwell[8] refers to the use of matched pairs of overlapping vertical aerial photographs in war-time wave surveys.

2. Automatic Pressure Recorders:

This method consists of placing a sensitive pressure recording instrument on the sea-bed some distance from the shore. The pressure differences due to the passing overhead of surface waves are converted to electrical impulses which are transmitted to the shore by cable where these are recorded as a continuous wave trace which may be automatically analysed into its component waves as in the machine described by

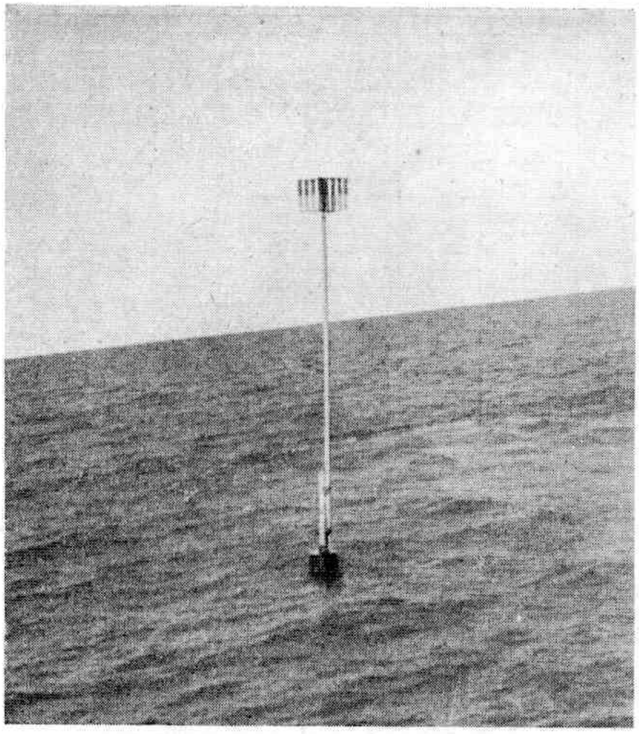


FIGURE 3. THE TYPE OF WAVE BUOY IN USE AT CAPE JAFFA, SOUTH AUSTRALIA.

Klebba[9]. Valembois[10] describes a French instrument which he claims will measure waves as small as 10 cm. in height with an accuracy of 1%. These recorders will only record surface waves with lengths greater than about twice the depth of lengths greater than about twice the depth of the instrument, but this fact may be used to filter out unimportant surface slop by choosing a suitable depth.

3. Visual Methods:

The Woods Hole Oceanographic Institution ship "Atlantis"[8] used a method of photographing waves against a graduated pole which was anchored to the bottom or held steady in deep water by means of a long baffle. Observations were made through a graticuled theodolite onto a row of dan buoys topped by graduated poles at wave recording stations established in England to aid wave forecasting for the Normandy invasion previously referred to.

A similar method is in use at Cape Jaffa, South Australia, where investigations at the site of a proposed deep-sea port are being undertaken by the South Australian Harbors Board. The author is indebted to the Board for permission to make reference to this work. Essentially the method is to observe the motion of a floating buoy through a calibrated telescope.

Observations are made twice daily to the Moresby Type buoy, which carries a slotted sighting mark on a 15-ft. oregon pole as shown in Fig. 3. A 100-lb. weight fixed to a 16-ft. pole beneath the buoy ensures stability, while 25 fathoms of $\frac{1}{2}$-in. chain and two 5-cwt. anchors are required for mooring. The telescope, shown in Fig. 4, has a magnification of 50 and is mounted in a hut on shore about two miles from the buoy, which is moored in 30 ft. of water. A graticule with horizontal lines one-hundredth of an inch apart is incorporated in the telescope, which has been calibrated so that the observed motion of the buoy in divisions can be converted to wave heights in feet.

The possible objections to this method are:

1. The inability to see the buoy during storms. This as yet has not proved a valid objection, as it has been possible to read the buoy at least once each day during the year or more since the buoy has been installed.
2. The inertia of the buoy and the effect of dragging tightly on its moorings may cause the buoy to considerably under-estimate the wave height, especially for shorter waves. Except for this case, the under-estimation would appear to be generally less than about 10%. The results of theoretical studies by F. John[11] applied to such a buoy were it floating freely give negligible factors for both the long and shorter waves recorded, but could not be rigidly applied to this case.
3. It is difficult to separate the characteristics of two separate coincident wave trains by observation. This, however, is only possible in certain cases with the costly automatic pressure recorders mentioned earlier.

WAVE SYSTEMS AT CAPE JAFFA

The practical approach to investigation of wave conditions at a harbor site may be illustrated by brief reference to the wave systems at Cape Jaffa, on the south-east coast of South Australia.

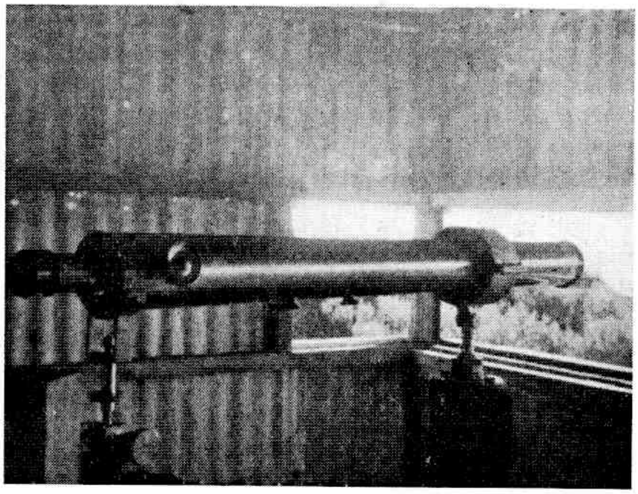


FIGURE 4. THE TELESCOPE USED TO MEASURE WAVE HEIGHTS AT CAPE JAFFA, SOUTH AUSTRALIA.

Fig. 5 shows that the only waves reaching the port will be generated by winds from any westerly direction. Wind records for the area show the only winds of consequence in force and duration to be from the north-west and south-west. These with the addition of a south-westerly swell provide the two important wave systems, namely, the N.W. storm and the S.W. swell, which may be aided by a S.W. or westerly wind.

1. North-West Storm:

This is a fairly straightforward case of wind waves generated by a limited fetch. The fetch in the N.W. direction is 100 miles to Kangaroo Island. Wind records for the area have been kept for some years, and during that time the worst storm recorded was in November, 1948. In this storm the recorded wind velocities could be idealised as 30 m.p.h. for 10 hours, 40 m.p.h. for 5 hours, and 50 m.p.h. for 2 hours. The combined effect of these winds for application to Fig. 2 is open to doubt. Bearing in mind the fact that the 50 m.p.h. wind is of short duration, it is probable that it would tend to blow the tops off the existing waves rather than increase them. Taking the 40 m.p.h. wind as significant and allotting a rather excessive duration of 12 hours to it, the resultant wave height would be about 18 ft. from Fig. 2. From Fig. 1 a 40 m.p.h. blowing over a fetch of 100 miles can generate only 16 ft. waves and this figure would govern.

It may be dangerous to base predictions on short term wind or wave records. Iribarren[3] suggests that 40 or 50 years' careful records are required before one can be reasonably sure that the worst storms have been recorded. Hence for such problems it is always advisable to seek expert meteorological advice on recorded and likely winds if such is available.

2. South-West Swell:

The belt of the "Roaring Forties" between South Africa and Australia is recognised as one of the roughest oceans, with almost constant westerly and south-westerly winds. Bigelow[12] quotes figures extracted from sailing ships' logs, which suggest that for more than half the year the waves in this belt are higher than 8 ft. and that at least 15% of these waves are over 20 ft. high.

The waves generated in this belt are recorded as a south-westerly swell at Cape Jaffa. The dimensions of this swell will depend on the following factors:

1. The wave characteristics which emerge from the disturbance.
2. The decay distance from the limit of the wave generating winds to Cape Jaffa, and the rate of wave height decrease and wave period increase to be applied.
3. The strength, direction and duration of following or opposing winds which may assist or deter the swell waves.

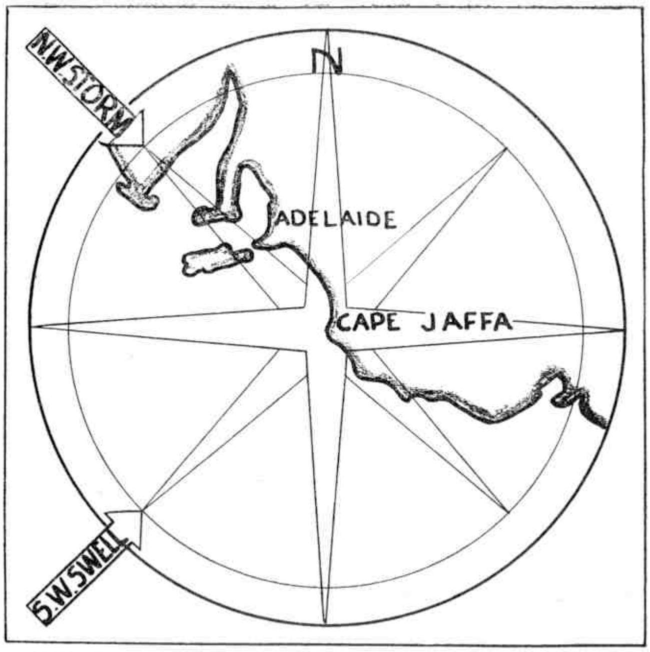


FIGURE 5. LOCATION OF CAPE JAFFA ON THE SOUTH-EAST COAST OF SOUTH AUSTRALIA.

The vast and inhospitable expanse of ocean south of Australia make it difficult to obtain adequate records of wind and wave conditions in this area, except for the occasional records of passing ships. Hence it is difficult to make more than a cursory analysis of the South-West Swell.

Observing a general limiting wave height of about 35 ft. in the West Wind belt, the problem is to find the height of the swell wave at Cape Jaffa. The decay distance is hard to estimate and will vary from season to season and from storm to storm. Charts in the British Admiralty Navigation Manual suggest that the limit of the westerlies is about 42°S. in the summer, whilst they extend to the coast in the winter. As an example, assume that this decay distance is 600 miles. Graphs published by Sverdrup[13] for a 9-second period wave indicate that the ratio of wave height at the end of decay to that at the start of decay would vary from about 0.4 with a 10 m.p.h. opposing wind to 0.6 with a 10 m.p.h. following wind over this distance.

That this approximation is of the right order for our case is borne out by the observance of 13-second maximum period swells at Cape Jaffa, which would have been 9- or 10-second swells before this distance of decay.

A useful rule which is roughly in agreement with Sverdrup's work is given in the British Admiralty Forecasting Report 1942 as follows: "Swell waves lose roughly one-third of their height each time they travel a distance in miles equal to their length in feet."

We can apply this rule to a 36-ft. high wave, with a period of 10 seconds and a length of 500 ft. at the edge of the westerlies. After 500 miles it would be 24 ft. high, and after 1,000 miles 16 ft. high. The observance of swell waves off Cape Jaffa with heights around 20 to 25 ft. rather indicates that the decay distance for the worst storms could be around the figure assumed.

SUMMARY

It can be seen that a complete wave investigation depends largely on the existence of adequate long-term meteorological data, mainly in connection with wind strengths, directions and durations. The references given from available literature testify to the amount of pure research being undertaken on the subject of wave characteristics.

The problems of ocean swell need careful treatment if encountered in harbor design, especially if there is a likelihood of aiding local winds. It should be remembered that waves will still grow under the influence of a wind at a considerable angle to the existing wave fronts.

Arthur[14] considers that with winds blowing at an angle of even 45° to the direction of travel equation 1, would become $H = \frac{0.17\,U^2}{g}$ or the waves could attain about two-thirds of their normal maximum height.

To provide an accurate and continuous check of wave systems, wave pressure recorders and analysers are required. The expense of this and of comprehensive investigations are well justified if there is any doubt of likely wave conditions. Failures of maritime works due to insufficient knowledge of wave conditions will bear this out.

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THE HARBOURS OF AUSTRALIA

By T. W. WHITTON, B.E.

"And seas but join the regions they divide."—Pope.

IN a recent issue of "The Dock and Harbour Authority" a quotation is made from R. H. Thornton's book, "British Shipping"—"the great ports of the world are mostly situated on wretched creeks and tidal estuaries, whose silting channels and shifting bars cost a fortune annually for every foot of depth maintained." This is only too true, but the harbour engineer is not to blame. Most ports have grown from small sheltering places and were never planned to become the large transport terminals they are to-day.

Possibly the greatest challenge man has experienced is the sea. In ancient times it represented a barrier between him and the end of the world, or so he thought. The desire to cross the sea and to see what was really on the other side, led to ventures further and further from the river mouths and bays in the frail craft of the times. Thus it came that larger and more seaworthy ships were built, and finally the seas were crossed, trade with the distant countries started, and the need for adequate harbours became essential.

There are several words used to describe places where ships may remain in safety for any purpose. "Port," "harbour," "haven," are three words that have different meanings in different countries. However, taking the Latin meaning of "port" as an entrance or gateway, and linking that with the passage of traffic from the sea to the land, it is logical to give to the word "port" the meaning "a place to which vessels may resort to discharge or receive their cargoes" (Webster). "Harbour" and "haven" have been used indiscriminately, but a distinction can be made with advantage—a "haven" being "a place where a ship may find shelter from a storm" (Fowler), and a "harbour" as a place giving accommodation for ships for any purpose whatever. Thus a haven is a natural shelter, whereas a harbour need not be and in general offers conveniences additional to that of protection from the elements of the sea.

It can be seen that "harbours" can become "ports" by the addition of facilities for discharging and receiving ships' cargoes. Here it is intended to deal only with "ports." There are again some words that have several meanings when used in referring to a port—"dock," "quay," "wharf," "pier." A dock in English use is an area of water surrounded by walls, either tidal or closed by a system of locks, and the ancillary sheds and stacking areas for the discharge or reception of cargo. In other words, ships enter this enclosed area and there, either while berthed alongside the walls or moored in stream, work cargo. The word "dock" is also used in the sense "dockyard"—a place where ships may be repaired either out of the water—dry dock, or not—wet dock.

A "quay" is a berth constructed of solid masonry or concrete as opposed to a "wharf" which is constructed of open pile work. A further distinction is that a "pier" or "jetty" projects out into the sea or waterway. It can be seen that a "pier" can either be of solid or pile construction, although in all cases it is generally known as a "pier." A "jetty" is much longer than a "pier" and can refer to a light pier for the discharge of passengers—i.e., from a ferry boat.

A port is a man-made structure consisting of quays, piers, wharves, docks, warehouses, rail and road transport facilities, cranes and other cargo handling equipment. It might necessitate costly dredging and construction work, and always presupposes a sufficient volume of traffic either inward or outward, or both. Before a port is built, trade for that port must exist—a port is built for trade and never can trade be made for a port. The attraction of trade from another port can be and is done—the fierce competition of the English ports before the war for the Midland trade and the rival claims of Boston, New York, Philadelphia and New Orleans for the rich Middle West industrial trade are examples. This competition compels port authorities to spend large sums of money on improvements and equipment and thus causes the changes that are so essential to progress. However, it is not always the expenditure of further capital that is the cure-all for loss of trade—the law of diminishing returns operates in port management as elsewhere.

It is seen that, firstly, the trade must be present, and secondly it must be kept and not allowed to wander away to other ports. Ports in the past grew from harbours and havens, and were used as assembling places for goods to be carried by sea. Roads were primitive and all trade was, as far as possible, sea borne at this time. With the advent of the railway, and more recently the motor truck, coastal sea transport has declined and many ports have fallen into disuse. It thus comes about that in some parts of the world there are too many ports. However, transport of passengers and goods cannot be regarded as a trade belonging exclusively to either the sea or the land. It is rarely that a port can be built starting from nothing

AERIAL VIEW OF INNER HARBOR, PORT ADELAIDE. Docks No. 1, 2, and 3 (projected) can be seen in the top centre of the photograph.

and then operate economically against land transport. A port is a huge financial undertaking, is completely immobile, and takes years to build. It is only a point of discharge or loading of ships —in other words, it is a centre for the transfer of goods from land to sea and vice versa.

Australia has some good natural harbours, but in general port facilities are neither adequate nor modern. Intrastate coastal trade rapidly deteriorated with the advent of the rail and road systems, and now air transport must take much of the interstate passenger trade. Railway competition is not easy to overcome—differential and tapering freight rates cannot apply to shipping. Rail and road transport is much more flexible, and except for bulk freights like coal and ore can handle freight more quickly.

It was when most of the small ports in Australia were due for rebuilding that the opposition of the land transport became most pressing. Thus these ports were allowed to fall into disuse and now are not suitable to handle much trade. It is only in the larger ports that any modern developments have taken place. Timber is still largely used, although Australian waters abound in such destructive marine organisms as Terodo, Chelura and Sphaeroma. In Western Australia and South Australia Jarrah is largely used, while in the eastern States Turpentine is most popular. Both these timbers are somewhat resistant to attack from marine organisms, but protective measures must be taken. Concrete is still in the experimental stage and is not yet in general use.

The development of ports in Australia has in general been haphazard. Sydney, of course, provided a natural haven that soon became a busy port. On the discovery of coal at Newcastle, trade developed, and in the absence of any opposition from rail or road a port was built. Similar beginnings can be found for every port in Australia—sometimes wheat, sometimes timber, sometimes a natural product like coal or iron ore or limestone, and always a port associated with the main administrative centre of the area. However, rail and road transport have provided strong opposition, which in several cases has killed the coastal sea trade and led to the abandoning of the ports. Due to the flat coastal plain and lack of natural harbours, the railway soon captured most of the coastal trade from the small ports on the east coast. It is only in Queensland, where the railways were developed later and to a different plan, that there are any number of ports. South Australia has an advantage in the two gulfs and the almost total absence of coastal railways, and so has many small ports.

Australia was divided into States without much regard for the natural development of the country—particularly the provision of harbours. There are few natural havens and no large coastal rivers, and, with the early advent of the railway, there was not the incentive to build costly port structures. Australia differs from most other countries in this respect. Of the capital cities only Sydney and Hobart are natural havens—and only Sydney can compare with the great ports of the world.

The tidal range in the principal ports of Australia is not sufficient to require the building of docks with entrance locks. As mentioned previously, there are very few natural harbours—Sydney, Hobart, Albany, Port Lincoln, and Gladstone are the main examples. The water in these harbours is deep and berths are of the timber pile type—either piers or wharves. Sydney, of course, possesses the most extensive wharfage system, but Hobart has the greatest depth of water, having over 60 feet at some wharves. Several of the other ports of Australia have been developed at river mouths, necessitating the use of much dredging and breakwater work.

Of the Queensland ports, Townsville is an artificial harbour with two long breakwaters projecting into Cleveland Bay. Some berths—served by rail—are provided alongside the eastern breakwater, but there are also two piers. The deep-sea port of Rockhampton—Port Alma—provides an interesting example of an island wharf. Due to the shallow depth of water the wharf was constructed some distance from the shore and connected thereto by a piled approach. The wharf is of timber, and the piles are protected from attacks by marine organisms by a cyprus pine cylinder filled with sand. The wharf is completely isolated from the city, and the only connection is by rail.

Mackay is another artificial harbour, and possesses the most modern sugar handling equipment in Australia. Except for Bowen and Gladstone, the other Queensland ports are river ports and have timber pile wharves. Concrete decks to these structures have been a recent addition in some cases.

The small New South Wales ports are nearly all river ports. They have timber wharves, and a limit is placed on the size of ships using the ports by the natural sand bar at the entrance. Although Newcastle was built on a river, it has now become almost an artificial port. Much dredging and reclamation work has been carried out, and a large swinging basin built. The wharves are timber pile structures. At Sydney there are both wharves and piers. Many berths have been rebuilt with concrete decks, and some new construction is to be built on reinforced concrete piles. In general Sydney wharves are not modern, but they compare favourably with the other Australian ports.

Port Kembla is an entirely artificial harbour, being built by arrangement with the Australian Iron and Steel Company. Two breakwaters enclose several piers, but the harbour is still open to weather from some directions, and work at the port is frequently delayed on account of this.

Melbourne is a combination of river and bay port. Large tidal docks have been built and are designed to increase the area of the river. Melbourne is one of the few ports in Australia where any planning on the "dock estate" idea has been introduced. There are also some riverside wharves and several piers at Port Melbourne. They are all of timber construction, but have recently had their wooden decks replaced by concrete. The berths at the other Victorian ports are timber piers, including the bulk wheat pier at Geelong.

Hobart has a large natural harbour, but there are very few berths. They are of the pier type, and the more modern have concrete decks. Difficulties have been experienced in construction, due to the great depth of water. Launceston is about 35 miles from the mouth of the River Tamar, but the overseas wharfage is at the entrance and of pier type. Timber has been used, but recently work is being constructed of reinforced concrete piles. Burnie is an artificial harbour with timber piers. Devenport is another river port, and again timber was used in wharf construction.

The harbours of South Australia built around the two gulfs needed very little protective works. The smaller ports consist of a jetty projecting directly out to sea in the general direction of the prevailing weather. The larger ports, such as Thevenard and Port Lincoln, are built in bays. Both ports have piers—at Thevenard an ambitious concrete pier was built, but due to lack of cover on the reinforcing steel much maintenance work has been necessary. Whyalla is an artificial harbour, but the main ore loading berth is in the open sea.

Port Adelaide wharves have been developed on a scheme first introduced on a large scale in Hamburg and other European ports. Very wide piers are featured, separated by narrow docks. In Port Adelaide the docks have been cut out of the river bank, leaving the piers of solid ground. This gives a semi-marginal wharf arrangement for an area of land some 1,800 feet by 1,000 feet, surrounded on three sides by wharves accommodating up to seven ships. On this land—really the pier—are the wharf transit sheds and warehouses, as well as a large open stacking area. Three of these docks have been constructed on the eastern bank of the river, but only two are in use. This method of development permits of the use of a type of wharf unique in Australia. The wharf design is also an adaption of a European idea with an "L"-shaped reinforced concrete structure supported at low water level on a system of timber piles with a solid sand fill behind. The piles are in solid ground retained on the river side by a wall of steel sheet piling. The result is a solid wharf protected from marine organisms and able to take considerable loading.

The Western Australian outports are all built on bays or inlets from the sea. The piers are of timber and in the North-West provision had to be made for the large rise and fall of tide. Fremantle is built on the entrance to a river and the wharves are of timber. The entrance is protected by two moles, but no sand bar forms. Albany harbour is built on a small inlet from King George's Sound. Although the Sound is a natural harbour, much work has been necessary in this inlet to provide wharves and piers. They are of timber, and in most cases very old. Bunbury and Busselton have jetties and are protected on the side of the prevailing weather by breakwaters.

The science of engineering is forever changing and in particular harbour engineering continues to advance. In the past century great changes have been made in the design of vessels and the method of propulsion, and, as can be expected, harbours have changed likewise.

The draught of ships has increased and the amount of cargo they carry has grown to such proportions that a single ship can now carry as much as a fleet of ships did a hundred years ago. The increased draught has set its own problems —channel deepening and widening and increased depth at wharves. However, it is the amount of cargo now carried in each ship that causes most of to-day's problems. Due to the slow "turn round" of ships and increased trade, more wharves are required, and old wharves need constant modernising to take the latest mechanical aids considered so essential to present-day cargo handling. Although the provision of wharf cranes is still an open question, and authorities are almost equally divided on both sides, the facts are that ships are larger and carry more. They remain in port longer and more mechanical handling equipment is demanded. On the passenger side increased facilities for Customs and immigration authorities are necessary, as well as provision for the many visitors witnessing a ship's arrival or departure.

In Australia at the present time, as well as much modernising and enlarging, several new ports are under consideration. At least one in each of Queensland, New South Wales, Victoria and South Australia. Each has its own problem —in some cases, as at Iluka on the New South Wales coast and Portland in Victoria, the provision of breakwaters, and at Cape Jaffa on the south-east coast of South Australia long causeways are necessary in order to provide adequate depth of water. Models will need to be built of ports—again Iluka could be mentioned—and altogether much research and planning will be required by harbour engineers for years to come.

Whether Australia will rise to the heights of nationhood dreamed of by the statesmen of the past rests to a large degree on her harbours—to an island continent they are an essential, and represent both the front door for visitors and the back door for traders. The ports must be able to handle the material required for the vast developmental schemes of the interior, and must also be adequate for the increasing volume of exports. Thus the harbours of Australia are a keystone to the nation's prosperity.

EDUCATION IN INDIA

By RAJENDRA SINGH

Introduction: While other countries have gone ahead under the leadership of their national governments and built up fine educational systems, India has been handicapped not only by the presence of a foreign government largely indifferent to the development of essential social services, but also by the lack of initiative of the people which is a natural consequence of political subjection.

Apportion the responsibility as you like between the people and the government, the fact remains that neither vision nor courage characterised the Indian educational policy during the last 150 years. We are to-day reaping the fruits of this long indifference and timidity of outlook.

Add to this the financial stringency. (The East India Co. in its yearly budget of 1813 could only sanction a sum of £7,000 for education for the entire country she ruled!) It is therefore not strange that out of a population of nearly 400 million, that is, 60 times that of Australia, only 45 million have some sort of an education. The wonder is not that India should be largely illiterate and educationally backward, but that in spite of these handicaps it should have produced scientists, philosophers, poets and statesmen like Raman, Vivekanda, Tagore and Nehru, who are able to hold their own with the best in the world.

Nursery Schools: There is at present no provision for nursery schools but in quite a few places these have been started and children are taken from 3 to 6 years of age.

Primary Schools: These are mostly government-sponsored and their aim is to impart basic education from 6 to 11 years of age.

Middle and High Schools: Middle school starts at the end of five years of primary school course. It lasts for three years. The high school course lasts another two years. They impart purely academic education and serve as feeders to the universities. About a third of those who pass the high school join the universities after matriculation. Two or three subjects, including English, are generally compulsory, while the remaining three or four subjects can be chosen by the students from either the arts group or science group of subjects.

Universities: There are in all 19 universities. In 1857 the first universities were established: Calcutta, followed by Madras and Bombay. The other towns and States quickly followed.

Indian universities are primarily administrative bodies and one of their main functions is to prescribe courses and conduct examinations. A certain amount of post-graduate work is organised in the universities, but the main part of teaching and post-graduate work is done in the numerous colleges affiliated to a university and scattered over vast areas. For example, the Calcutta University controls about 60 colleges.

The four years' graduation course is divided into two stages: Intermediate and then B.A. or B.Sc. English is a compulsory subject and also the medium of instruction.

The post-graduate department presents the best aspect of university education in India. Two years' work leads the student to his master's degree. The percentage of failure is small, as only those who are keen and capable have been able to come up so far. The master's degree is the minimum required qualification for those who wish to take up teaching as a profession in the universities.

Professional Education.

Medical: There are about 25 medical colleges in India, which turn out about 1,000 graduates per year. The standard is good and the medical degree M.B. is a registrable qualification in U.K.

In addition there are over 20 medical schools, which turn out another 1,000 Licentiates per year.

In one of the four colleges the double shift system is being tried so as nearly to double the usual number of graduates with the present equipment. (Ratio of doctors to population is less than 1 to 7,000.)

Besides facilities for M.S. and the M.D. degrees, post-graduate courses in special subjects are available at different universities and research institutes of medicine, e.g., tuberculosis, opthalmology, obstetrics, gynaecology, public health, radiology, etc. Foreign experts are available for teaching in some of these internationally known institutes.

Though hospital work is in the M.B. course, yet post-graduate hospital work is a necessity before the medical graduate starts practice.

Examinations are very strict and admissions to first year is by competition.

Engineering: There are about 28 engineering colleges of university status, and about 25 technological institutions of non-university grade. Degree courses in civil, mechanical, electrical, metallurgical, architectural, chemical and other branches of engineering are provided in most of the university colleges. Colleges for mining are situated in the mining districts.

Admission tests are the rule, and only selected students (by written and viva voce examinations) are admitted.

The well-known engineering colleges are small villages in themselves, with independent water, electricity, sewage, ovals, and swimming pools.

Boarding and lodging is compulsory for both staff and students, for whom planned houses and hostels are built within the college compound. All facilities are provided, including medical attendance and hospital within the compound.

General working hours are 7—11 a.m. and 1—4 p.m., with half-day on Saturday—a total of 39 hours a week. Workshop, laboratories, library and so on, being in the compound, are easily available at all times. A real contact between staff and student exists even on the playground —a truly tutorial atmosphere.

The sites are carefully chosen, well out of town, generally on the banks of a river. One of the colleges in Calcutta is on the River Ganges, with the Calcutta Botanical Garden next door, providing a picturesque locality for fresh air and relaxation for students.

Examinations and courses are strict. Any student failing in the first year is automatically denied repetition. Quite a number are thus weeded out. Sessional work in laboratory and workshop carry credit in the examination. Both theoretical and practical examinations are held every year.

Professors of many nationalities are found on the full-time staff to teach and supervise research in important fields of engineering, for example, Italian professors in architecture or a German professor in metallurgy, and so on.

Workshops and laboratories are quite large, having both old and new equipment (most of the colleges have received good shares of disposal machinery.)

After the degree examination students must put in two years' apprenticeship in recognised workshops and industries. A full-time engineer on the staff is in charge of placements and supervision of students while under training.

Many large industrial concerns run their own training institutes. For example, Tata Iron and Steel Co. hold yearly competitions to select engineering graduates and impart intensive general training in their various departments for two years. In the evening, trainees attend specialised lectures from the departmental experts of the steelworks. These experts are some of the top ranking specialists of the world, many of them from U.K., U.S.A., and the Continent. After successful completion (if found suitable) permanent jobs are offered to the graduates.

While under training, the students are not treated nor paid as employees, and therefore devote all their time to learning.

Agriculture: Though India is mainly agricultural, yet this department of education has perhaps received least attention. The Indian Council of Agricultural Research has been promoting a number of schools and colleges to fill this gap.

Scientific Research: Until recently research work was confined to the major universities. At present there are about 40 independent institutions devoted only to research.

The Indian Council of Scientific and Industrial Research is assisted by 24 Research Committees, covering 24 different subjects having some bearing on industry.

A chain of national laboratories is being set up, of which nine are already working:—

National Chemical Research Laboratory: This is under the supervision of Prof. McBain, of Stanford University, California. It has seven divisions: Inorganic Chemistry, Physical Chemistry, Chemistry of High Polymers, Organic Chemistry, Bio-chemistry, Chemical Engineering, and Survey and Intelligence.

National Physical Laboratory: Modelled on the U.K. National Physical Laboratory, it is the custodian of standards of mass and length. Among its 10 divisions are: Weights and measures, applied mechanics, materials, heat and power, optics, electricity.

Dr. K. S. Krisnan, F.R.S., who was associated with Dr. C. V. Raman in the discovery of "Raman Effect," is the Director of this laboratory.

At present some of the work going on includes the construction of equipment for the study of Beta-rays, quartz clock, etc. Other work in hand includes investigations in the field of fundamental physics, relating to determination of nuclear magnetic moments by resonance of microwaves, dispersion and absorption of ultrasonics in liquids.

Fuel Research Laboratory: Dr. J. M. Whittaker is directing investigations in furnaces, combustion and boiler plants, coal washing, briquetting, hydro-carbons synthesis, plastics; I.C. combustions, etc.

Metallurgical Laboratory: All aspects of metallurgical research are undertaken, including ores, minerals and refractories. Five divisions cover physical metallurgy, metallography, chemical metallurgy, physical chemistry and refractories. A special feature of this lab. is its collaboration with the steelworks of Tata's, the Research Building being situated next door to the steelworks. One result of its work is a scheme for substitution of manganese for nickel in austenitic steels.

Drug Research Institute: This is directed by Sir Edward Mellanby, one of Britain's foremost medical scientists. The five divisions are: Chemistry, botany, pharmacology, bio-chemistry, microbiology and chemical science.

The other Research Institutes are in Food Technology, Roads and Building, Leather and Electro-chemical.

Apart from these, as mentioned earlier, there are some 30 more Research Institutes on subjects like Agriculture, Sugar, Forestry, Fishery, and so on.

Art and Culture: Coming back to general education, we find that in addition to metaphysics, three of the forms of expression of the Indian mind, music, dancing, and painting and sculpture, are also not neglected. There are about 20 art schools in India, where painting, sculpture and allied subjects are taught. Much more numerous are the music and dancing schools and cultural centres.

Adult Education: Mass literacy drives in villages all over the country have been organised. Schools and libraries have been specially opened up for this purpose.

Experiments in Education: The awakening for education naturally brought about a new outlook, which is beginning to affect our work, directing us to enlarge the scope and enrich the content of education—not merely to train for jobs of clerks and junior administrative officers in Government Services.

Tagore's Santi-nekatan: Under the above observation comes this world-renowned institution. It is international in its composition, having teachers and students from Europe, U.S.A., and other countries. It is not bound up in government red tape or to the rules and regulations of any old university. Education is imparted in its true sense. Students are given opportunities of studying social services and work in the villages. Cultural development is encouraged. It is a garden college. Lessons are given indoor or outdoor under beautiful trees. A great sense of peace and oneness with nature pervades the whole atmosphere of study.

Gandhi's "New" Education: Gandhi pointed out that while life is practical and productive, the school is mainly of bookish learning. It therefore fails to train students for the demand of an active, social and practical life.

Mahatma Gandhi presented the revolutionary idea, which threw a stone into the nest of academicians, that all primary education must centre round some kind of craft work and every item of knowledge that is taught should be closely related to the basic craft chosen. It must be clearly understood that it is not teaching a trade to the child—no, this type of education, starting with the "whys and wherefores," studied under careful guidance, will lead the child's attention to the ever expanding regions of knowledge which need not be thrust upon him like a ready-made and unwelcome medicine. Rather, responding to a felt need, it should take him to the fields of natural sciences, history, geography and so on. Gandhi further believed that the product so made by the child should be marketable, as it will be the acid test of the efficiency of the teacher and the carefulness and intelligence of the student. If the products of industry through which education is imparted are not worthy of being used by the community, then there must be something wrong either with the teacher or the taught.

Naturally, specially teachers are required for this type of education, and already centres have been opened.

Students Abroad: The Government has been sending students abroad for specialisation in different subjects, mostly scientific and industrial. Since 1946 over 1,500 scholars have been sent abroad for advanced work, including medical, agricultural and teaching. These scholars are under contract to serve the Government for five years after return. While overseas in U.K., U.S.A., or other countries, their bursary is equal to Rhodes Scholars in Oxford, and provision is made for them to travel extensively.

Students are also going abroad on various other schemes, while a number of foreign students are invited and are studying in various Indian universities. Quite a number of these are UNESCO scholars, who are to be found in various parts of the world. Exchange of scholars is encouraged.

But all of these factors, however, are only a part of the "One World" theory advocated by eminent men like Wendell Wilkie. The savage says, "Thine is mine." The next higher says, "Mine is mine and I shall hold to it." But the enlightened says, "Mine is thine—come, let us share it." The world of to-day thinks in this fashion. Only recently Bertrand Russell propagated the same theory.

So, with such encouragement, there is no reason why illiteracy should not be eradicated from India. India has made good advances in higher education, but mass literacy is required.

U.S.A. raised the literacy of the Philippines from 2 to 55% in 40 years; U.S.S.R. raised its own from 5 to 77% in 20 years. Independent India, as yet only three years old, has taken up the challenge and boldly faces the problem with confidence and hope.

THE STATUS OF ENGINEERING

Contributed by
The Association of Professional Engineers, Australia.

WHAT is an engineer? Many of you will hope that this year will see the end of an arduous course of training and you will justly feel that you have earned the right to be known as an engineer. You may be bewildered at the many grades of society that claim the same title. Some years ago the Engineering News Record made a collection of about three thousand callings which aspired to this classification. Many of these had a humorous aspect, "Tonsorial Engineer," "Culinary Engineer," and so on, but they indicate that this term "Engineer" carries the respect of the community. Many of the callings have scant right to use the assignation. There are others justly entitled to use it, and these include, for example, marine engineers and those who are qualified to drive and physically care for engines. To avoid confusion with the artisans and others, the terms "Chartered Engineer" and "Professional Engineer" have been established for those who have the benefit of a more extensive scientific training.

To maintain and increase the prestige of the engineer in the community, the Association of Professional Engineers was formed early in 1946. The aims of this Association are devoted to the interests of the employe engineer. The need for such an organisation has become apparent throughout the world. In Great Britain, Canada, the United States of America and New Zealand responsible engineers have joined together to develop these activities, either within the bounds of existing organisations or in new bodies set up for this purpose. The A.P.E.A. has undertaken this activity in Australia, and in its brief four years has achieved much.

Most engineers find employment in industry or in public undertakings, and but few set up on their own. While this has allowed the profession to give notable service, the status and financial rewards accorded to engineers have been inferior to those of some other learned professions. This state of affairs is illogical, and the A.P.E.A. aims to win proper recognition for the engineer and his work.

Quite early in its career the Association sought registration under the Commonwealth Conciliation and Arbitration Act (1904-47). The application was strongly opposed by a number of organisations, which claimed that they adequately represented the engineer under the Act. All these bodies had some engineer members. The engineer was, in practically all cases, caught up in an "omnibus" body which, while using his prestige, had to devote its energies to sponsoring the interests of a majority of members of non-professional standing. The Association was able to establish that engineers outside of the Commonwealth Public Service could not, for industrial purposes, conveniently belong to any of these organisations, and registration was granted.

The activities of the Institution of Engineers, Australia, are well known through the regular technical meetings of both the Senior and the Junior and Students sections. The Institution has, over the years, done much to weld together the profession in Australia. By its nature, representing both employes and employers, it is not able to go to the Arbitration Court. This is a field of activity for the A.P.E.A.

Contrary to some hopes, the passing of the years has not seen due recognition for engineers come to them automatically. Indeed, a lack of united assertion in this direction has been taken to indicate the acceptance by engineers of a lowly position in the professional field. The Association, in tackling this problem, has made approaches to the Commonwealth Arbitration Court and actions are being vigorously pursued.

Growth of membership of the A.P.E.A. was at first slow. Up to November, 1948, some 470 members had been enrolled. Since that date, when registration was granted, there has been a steady increase, and at present there are 1,800 members and an inflow of over 100 a month.

One of the early activities involved considerable research into the conditions of employment that should be sought for the profession. Not only was this investigation applied to salaries, but all aspects of employment were examined. From this work logs of claims were developed for service on employers. Considerable dissatisfaction with conditions of employment existed in the local government field in several States, and a log was served on about 900 municipalities. This operation, after extensive negotiation, is nearly concluded, and the Association has been successful in improving the lot of the municipal engineers in Victoria. It is hoped to extend this award to other States, including South Australia, in the near future. Even in this action opposition came from other registered organisations which had, by priority of establishment, some engineer members.

Other logs of claims have been served and action is planned wherever members of the Association are employed under conditions below the standard sought. Proceedings are also in hand to seek a revision of the terms of registration whereby members of the Commonwealth Public Service are at present excluded from membership.

This brief review of the A.P.E.A. is presented to inform readers of its aims and purposes, and to show the value of membership to the engineer. The standards required are those for corporate membership of the Institution of Engineers, Australia, less the term of practical experience. The examinations for the engineering degree course fully qualify for admission.

The A.P.E.A. is wholly in the hands of the engineer members. All offices are held by annual election, and the Association is striving to maintain the high ethical standard of the profession in all its activities. The greater the number of members the more powerful will its influence be.

The need to improve the salary and the status of the engineer by arbitration and negotiation has been stressed. This is not, however, the limit of the work of the Association. Many other activities are visualised. At present a committee is investigating the desirability of restricting the practice of engineering to those adequately trained to it. The late Professor Sir Robert W. Chapman, C.M.G., M.A., worked on these lines both within and without the Institution of Engineers, and the Association will continue to operate in the interests of the profession. Recently the A.P.E.A. joined with the Institution in Victoria in successfully opposing legislation which aimed to reduce the status of engineers in the municipal field.

Other professions have organisations that protect their interests within the social structure. The B.M.A. and the Law Society have each served their professions well, and they have derived their strength from universal membership, from the loyalty of their members, and from the high ideals maintained. Given full support, the Association of Professional Engineers, Australia, will fulfil the same purpose for the engineer.

AN EXPERIMENTAL AIR CONDITIONING PLANT

By B. DOWNS, M.Eng. (Liverpool)

THE experimental air conditioning plant nearing completion in the Holden Mechanical Engineering Laboratory was designed as an honours project, under staff supervision, by R. J. Stapledon.

Air conditioning finds two main fields of application, comfort conditioning and process conditioning, each field requiring a custom built conditioner if ideal operation is to be obtained. Even in these two fields, the particular applications may call for design changes, the requirements for theatre comfort conditioning being different from, say, those of an ocean liner or a private residence. The industrial process field is even wider, ranging from electrical insulation manufacture, where high temperature and low humidity are necessary, textile processing requiring high humidity, engineering metrology with its rigorous demands on temperature control, to the low temperature fields of food storage.

"Full" air conditioning caters for temperature and humidity control, and also such items as dust and odour, and even noise removal, ventilation, and so on. Comfort conditioning permits of comparatively large "differentials" or variations in both temperature and humidity as may be seen from Fig. 1. Normal individuals maintain a body temperature of about 98.6°F., and the ability to feel comfortable in quite a range of air conditions is due to the conditioning system endowed by Nature upon each human body. The body temperature is maintained by balancing the rate of heat loss by convection, radiation, and the evaporation of moisture from the lungs and the body surfaces, with the rate of internal heat generation by metabolism. Under temperate surroundings, this regulation is achieved by variation of the metabolic rate and simultaneous variation of the blood circulation near the surface of the skin which affects the skin temperature. This control is not sufficient under tropical conditions or when the metabolic rate has been accelerated by heavy physical exertion. Emergency regulation then results, as is indicated by abnormal activity of the sweat glands. It might be thought that process conditioning, with its call for close control of temperature and humidity, would outweigh comfort conditioning in its demands on equipment. The comfort conditioning engineer, however, must face up to vagaries of human nature. We all know the fresh-air fiend, who opens every window wide, or the folk who can feel a draught almost before it arrives. Though these extreme cases may never find comfort, except perhaps in psychology, we are all conscious of odour and stuffiness, and susceptible to strong draughts, so that good conditioning must avoid these pitfalls.

The plant in the Mechanical Engineering Laboratory has been designed to condition one small room, with provision for outlets to a precision workshop and a metrology room. It is capable of meeting any type of "load" and is expected to achieve close control of temperature and humidity. Dust and odour removal will be obtained, whilst ample provision has been made for fresh air changes for all outlets. Before dealing with the unit, a word on temperature and humidity control, together with the statement of a few psychrometric concepts, will not be amiss.

Air consists of quite a mixture of elements and compounds, including oxygen, nitrogen, hydrogen, carbon dioxide, and a few rare inert gases and also water vapour. For the purpose of most thermodynamic treatments air may be regarded as a mixture of "dry air" and water vapour. It is customary in psychrometry to refer all quantities to 1 lb. of "dry air." For example, specific humidity which measures the ratio of

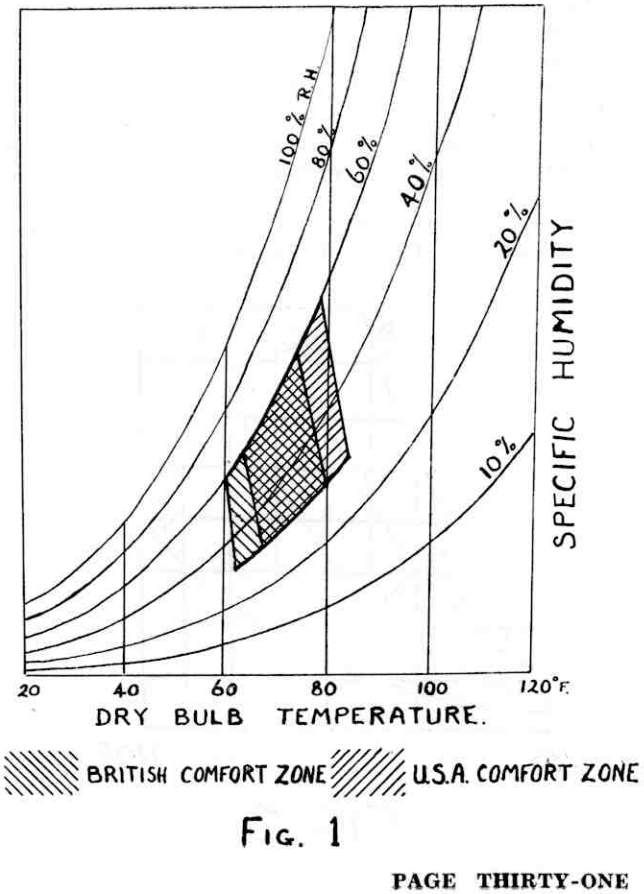


FIG. 1

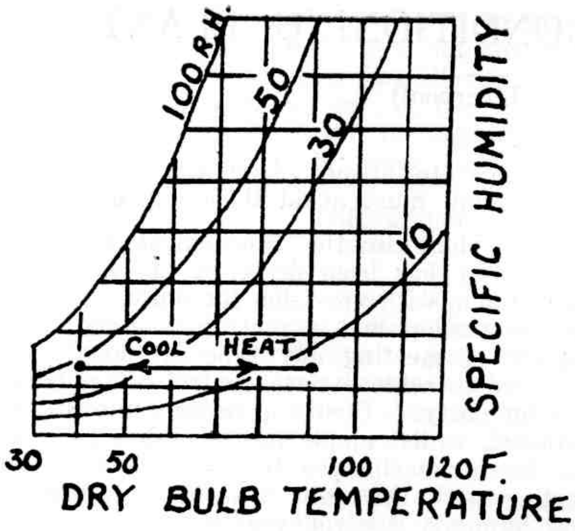


FIG. 2

weight of water vapour to weight of associated dry air is expressed in grains per lb. of dry air (7,000 grains = 1 lb.). The ability of air to "hold" moisture increases rapidly as the air temperature rises. The moisture content of unsaturated air is less than the amount which the air at that temperature could hold, the ratio being the percentage humidity which, for all practical purposes, equals the relative humidity (R.H.).

Heating, which is one step in conditioning, may be accomplished in a variety of ways, steam coils and electric strip heaters being the simplest. Cooling employs water or chilled brine cooled coils, although direct mechanical refrigeration is frequently adopted. A recent addition to cooling methods is absorption refrigeration, using lithium bromide and water. In general, the water vapour in the air exists as low pressure, highly superheated steam. Direct heating merely increases the superheat, whilst cooling effects the reverse. Extreme cooling may bring the mixture to a condition of saturation when the dew point temperature is reached. Further cooling below the dew point results in moisture deposition, the process then becoming a combination of cooling and dehumidifying. Local cooling, producing visible evidence of this moisture deposition, is a common occurrence on the inside surfaces of windows when the air outside is appreciably colder than that inside. This system of moisture removal is utilised in some air conditioning plants, but, since reheating of the air is necessary, the refrigeration capacity becomes considerably greater than that required to handle the air cooling load unless a special heat exchanger system is adopted.

By now the reader will know that any simple heating or cooling process, besides altering the dry bulb temperature of the air, also alters the relative humidity. Individuals and processes are sensitive to relative humidity, so that humidity control really implies relative humidity control. Although air conditioning is complicated by the intertwining of temperature and relative humidity, the control instruments employed are limited to thermostats, which detect changes in dry bulb temperature, and humidistats, which are sensitive to alterations of relative humidity. A lesser known instrument is the Eupatheoscope, which is almost human in its operation. Body comfort depends on the rate of heat loss from the body, and this in turn is a function of the "equivalent temperature," which is measured by the Eupatheoscope. The scale of equivalent temperature is essentially a refinement of the sensation scale. In terms of our sensations we may say, "It is colder now that the sun has gone in," or "Come round the corner, it will be warmer out of the wind." But when we attempt to

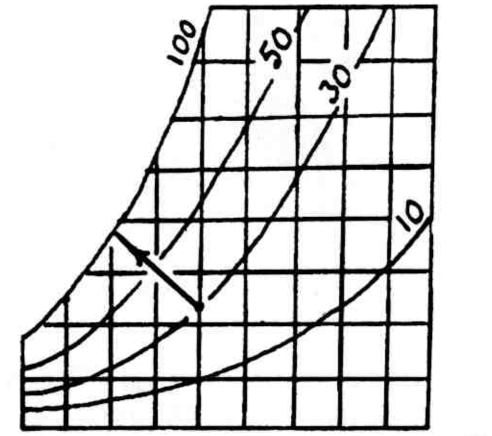


FIG. 3

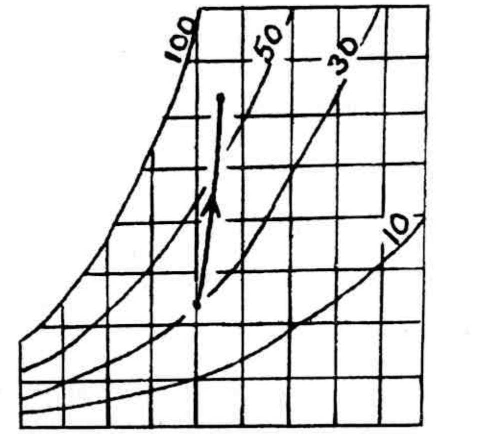


FIG. 4.

express "how much colder" or "how much warmer," the need for the "equivalent temperature" scale becomes apparent. Since human sensations are affected by diurnal and seasonal acclimatisation and are notoriously variable and individual, it is not surprising that the Eupatheoscope is not included amongst air conditioning control instruments.

The application of control instruments may easily bewilder those who first enquire, "How does it work?" The major difficulty lies in the natural assumption that a thermostat, as its name implies, is a temperature control device. This is quite correct when only one control is employed, or when one section of a controlled plant is isolated for examination. A conditioning plant is judged, however, on the ultimate effect that it produces in the conditioned space, so that, whereas a thermostat may maintain the temperature constant at one point of a conditioner, it may have no effect on the control of temperature in the conditioned space. This is due to the ability of succeeding conditioning processes to alter the air temperature irrespective of the control exercised by this thermostat. A common illustration of this is found where a thermostat is placed immediately behind a cooling coil which it controls. This is a "dew point" thermostat which, in conjunction with the remaining controls determining the final dry bulb temperature of the air, effectively controls the relative humidity. The use of thermostats to achieve humidity control is a feature of many installations.

Humidification and dehumidification refer to increase and decrease, respectively, of the specific humidity. Air conditioners may be called upon to combine heating or cooling with humidifying or dehumidifying in any combination and proportion. Comfort conditioning is generally achieved by heating and humidifying in winter and cooling and dehumidifying in summer. A number of methods are used to effect air condition changes, and, to illustrate their operation, diagrammatic representation is most convenient. The psychrometric chart, on which are shown lines of constant specific humidity, relative humidity, and dry bulb temperature is universally used.

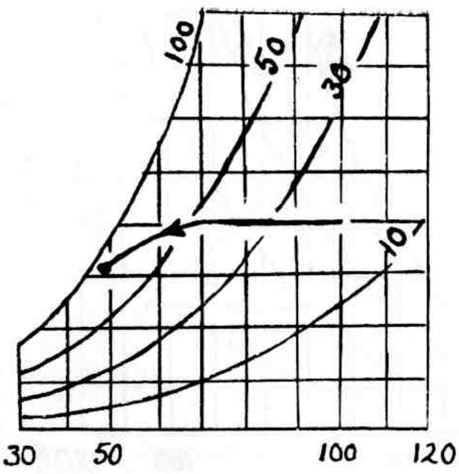


FIG. 6

The usual conditioning processes are:—

1. Heating or cooling without moisture change —effected by steam coils or electric heaters, or by water cooled coils respectively, illustrated in Fig. 2.
2. Cooling and humidifying by spray—effected by spraying recirculated water across the air flow, illustrated in Fig. 3.
3. Heating and humidifying by spray—effected by heating the recirculated water of case 2, illustrated in Fig. 4.

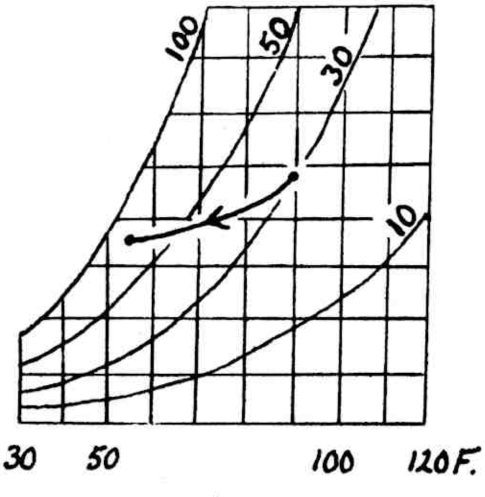


FIG. 5

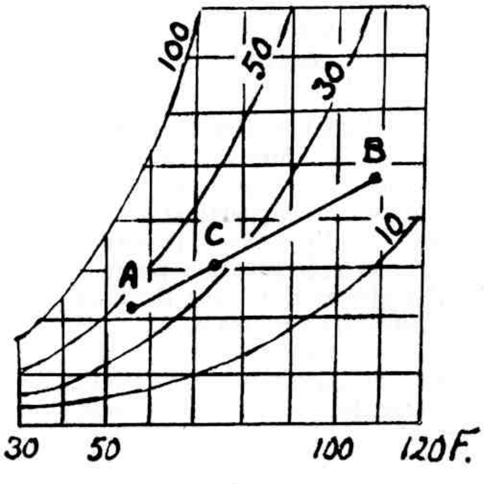


FIG. 7

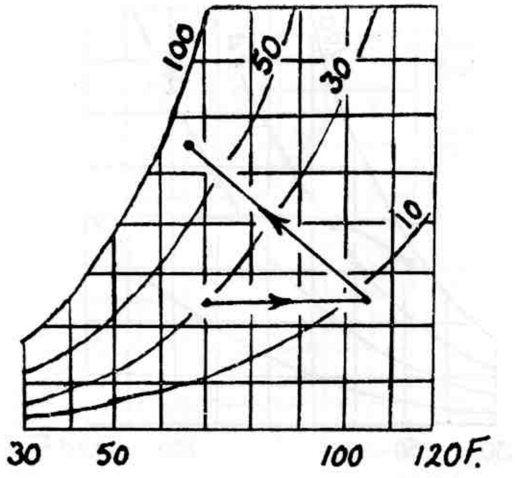


FIG.8

4. Cooling and dehumidifying by spray—effected by chilling the recirculated water of case 2, illustrated in Fig. 5.
5. Cooling and dehumidification by coils—effected by circulating refrigerant, usually Freon 12, which evaporates within the coils, illustrated in Fig. 6.
6. Mixing of air at different conditions—effected by control louvres, illustrated in Fig. 7, in which A and B represent states of air prior to mixing and C the state of the mixture.

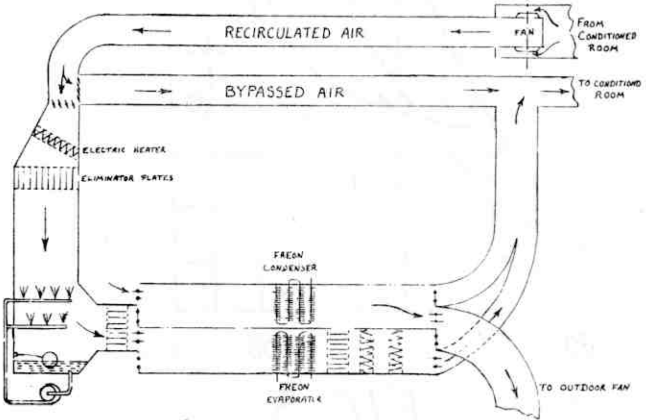
One combination of some of these processes is worthy of special mention, this is heating followed by cooling and humidifying by spray. The purpose of the initial heating or "tempering" operation is to enable the air to pick up more moisture in the spray chamber; this can be seen by comparing Fig. 8 with Fig. 3. Reheating coils usually follow this combination, and these three processes, in the sequence given, are capable of meeting the requirements of temperature and humidity control for winter comfort conditioning.

The plant installed in the Holden Laboratory uses this combination for heating and humidifying loads. Electric strip heaters temper the air, which next enters a vertical spray chamber or washer and finally passes through the condenser of a Freon refrigeration plant. The flow of heat to the air, as it passes through the condenser, is assisted by the use of extended surface tubes in the condenser construction. The refrigerator is kept in operation by an outdoor fan which draws air through the evaporator before discharging this cold air outside the building. By transferring heat from this "outdoor" air to the air undergoing conditioning, the plant is utilising the heat pumping function of a refrigerator.

When handling cooling or dehumidifying loads, the conditioned air leaving the spray chamber is switched to a new path, along which it passes through the evaporator and then through electrical strip heaters for reheating. Simultaneously the outdoor fan is enabled to draw air through the condenser, whilst an auxiliary water cooled condenser can be brought into service to cope with heavy cooling loads.

The plant is intended to provide practical illustration of the basic principles of air conditioning. Flexibility of construction and operation will permit investigations to be made into many aspects. A system of completely automatic control is embodied with each control signalling its operation on a central control panel. The main temperature control is effected by a modulating motor, which steadily increases or decreases the air flow through the conditioner, the remaining air being sent through a by-pass duct. Simultaneous alteration in refrigerator compressor speed is possible, giving good operating conditions at all loads. Each of the automatic controls is provided with a manual override, and the student may operate the unit in any way he may desire, since protection devices will shut the plant down whenever dangerous conditions are approached.

At the moment of writing, the unit is almost complete, although the lagging of the ductwork has not been put in hand. One project on which the plant will be used in the near future is the testing of a locally produced comfort conditioner which will be supplied with air of diverse states by the unit.



EXPERIMENTAL AIR CONDITIONING PLANT

ENGINEERING CURVED SURFACES

By J. P. Duncan, B.E.

GEOMETRY is so familiar to the engineer as a fundamental tool by means of which his theoretical concepts can be represented for ready comprehension by others, that it is rarely singled out as a topic of direct as opposed to indirect interest in engineering application. It is true that since the Greeks formulated the system of geometry which we use for practical purposes to-day, others have developed its theory to a high degree and have even found the subject sufficiently fascinating to invent new systems and to add to the number of dimensions. If you are one who, upon first acquaintance with compass and rule, found some of that fascination in discovering the properties of plane figures, then you might also find a similar interest in the properties of curved surfaces and their economic implications in the field of sheet metal construction.

The curved surface is, of course, most frequently used to represent, by means of lengths, a relationship between three quantities involving all the fundamental dimensions concerned in a physical problem. In such cases, the relationship referred to is usually fixed by factors independent of the geometric representation. By the location of points in a co-ordinate system either algebraically, graphically, or with the aid of a model, the surface is defined. For many, at least, the significance of the relationship is clarified by actual inspection or visualisation of such a surface.

On the other hand, some knowledge of the properties of curved surfaces and dependent practical techniques is required in order to define and construct in sheet metal a curved surface having arbitrarily curved boundary lines in space, possessing at the same time satisfactory aesthetic appearance or aerodynamical characteristics and being capable of economic manufacture. This is the type of problem that arises in the automobile, aircraft and shipbuilding industries in each of which design involves the definition of the outer surface of the unit in addition to strength, aerodynamical or hydraulic considerations. In the case of the automobile, the definition and construction of the outer surface forms the major part of the designer's and certainly the body builder's task. In each of these fields, the medium of construction is normally flat sheet metal, which must be mechanically worked into a system of panels giving the desired overall body shape on assembly.

The process of designing a curved surface is often called "development," a term loosely applied to the design of all types of surface. The usual and long established practice is to set about drawing full size, on metal or masonite sheets with specially prepared surfaces, the desired sections of the surface by three mutually perpendicular planes. It is then necessary to develop or define the surfaces joining these principal sections so that they give adequate clearance on internal obstructions, such as engines or mechanical gear. They must also be free from bumps and flats which give objectionable discontinuities in the highlights of a polished panel and must lend themselves to practical manufacture. From this last point of view the body as a whole must be sub-divided into sections or panels, each of which is considered separately.

A number of considerations may determine the control outlines mentioned above. In the automobile, appearance, particularly in side

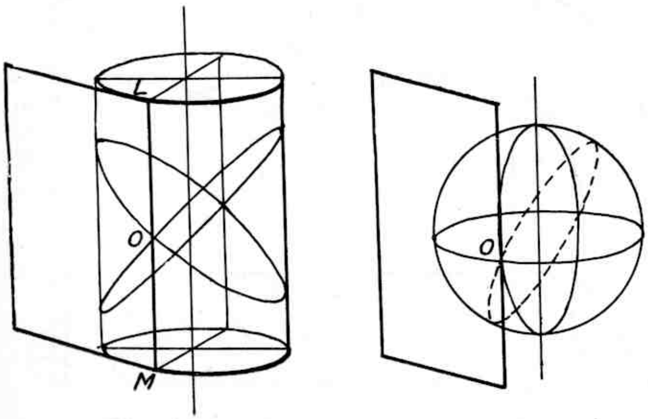


FIG. 1.

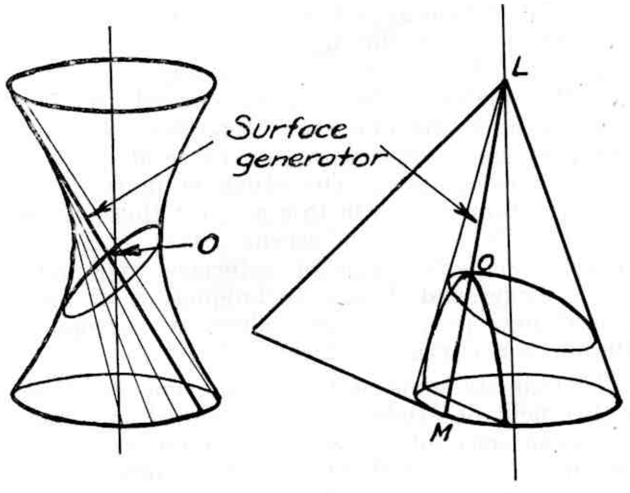


FIG. 2.

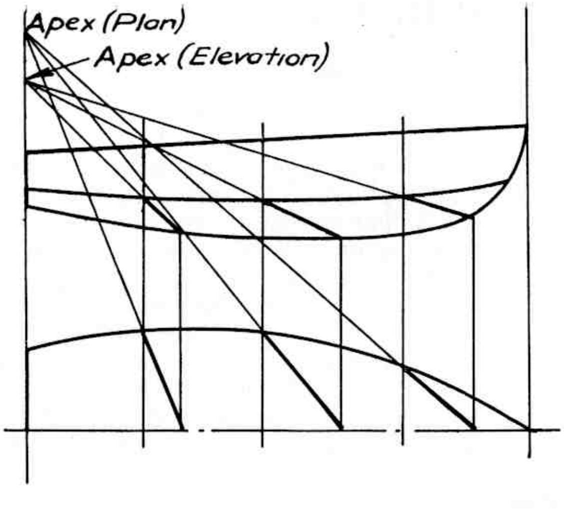


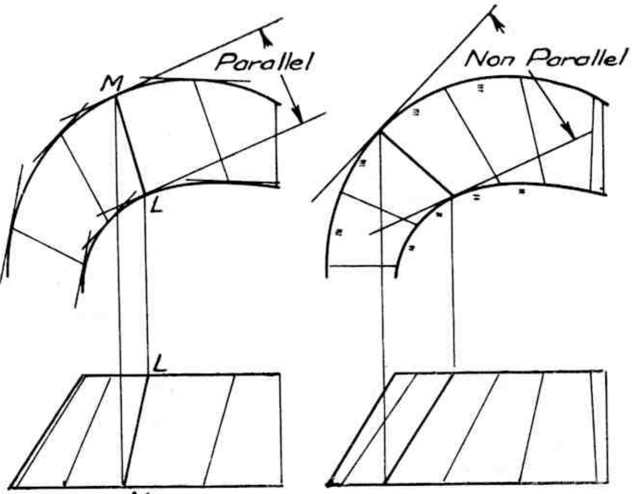
FIG. 3.

elevation, largely controls the situation. Preliminary side elevations are prepared on vertical boards and the control outlines are viewed, criticised and modified to a final form. In aircraft and shipbuilding, most external surfaces such as aerofoils and submerged hull are defined by aerodynamical or hydraulic considerations, although the fuselage of an aircraft leaves room for a certain amount of arbitrary choice of line. To remove the arbitrary nature of some of these control curves, parabolas, ellipses and other curves, whose algebraic equations are known, may be used in combination as control curves. This often permits the whole surface to be algebraically defined, which is a great advantage in large bodies, and is a method widely used by American aircraft builders. With the automobile, however, the demanded complexity of the control curves calls for graphical or even trial and error methods.

In naval architecture the method of defining the shape of a ship's hull by means of buttock, water and station lines has been well established. The curvature of the hull is, in the main, so small that the frame can be largely sheathed with flat plates. Spherically curved surfaces do not assume the importance or offer the problems they have done with aircraft and automobiles, where spherical curvature is more often called for than not. On this account these latter industries have within recent years borrowed the ship builder's frame of reference and many of his terms and design techniques and have devised new graphical and algebraic means of defining the curved surfaces.

To indicate some of the major considerations in this field of study, some simplified examples have been selected. For practical purposes surfaces may be classified into two types, often called "developable" or "non-developable" but more appropriately described as "cylinderically curved" or "spherically curved." These are represented in their basic form by the cylindrical surface and spherical surface of Fig. 1. The first surface is characterised by the fact that the tangent plane to the surface at O touches the surface along a line LM, the generator of the surface, whilst the second is characterised by the fact that the tangent plane at O touches the surface at this point only. The first surface can be developed or formed by wrapping the tangent plane in the form of a sheet of metal round the instantaneous tangent line until the surface is completed. The second surface is a special case among a wide variety of surfaces having curvature in all directions. It cannot be formed from a flat sheet of material by means similar to the previous example, but demands means of stretching the sheet in the vicinity of the point of tangency by plastic flow. The tools and equipment required in the former case are standardised and relatively inexpensive, but the latter involves a large capital outlay in machine tools, presses and dies to produce such a surface in quantity. If, therefore, means exist for bridging an area between specified boundary curves with a developable surface instead of an undevelopable one, the advantages are obvious.

It should not be concluded that a surface containing one straight line through a selected point and therefore having no curvature in this direction is necessarily developable. Consider the cone and hyperboloid of revolution in Fig. 2. The first mentioned, a developable surface, has no curvature in the direction of the slant height which is also the line of contact of the tangent or wrapping plane. The second, a surface of some importance in gearing, is generated by either the rotation of a hyperbola about an axis or by the rotation about an axis of a line skew to that axis. Hence this straight line generator



Developable

Non Developable

FIG. 4

will in turn pass through all points on the generated surface, always lying within the surface. The surface is not developable, however, for a tangent plane does not contact the surface along this line.

Fig. 3 shows one construction which could be used to define the bottom of a so-called V-bottom boat as portion of a conoid (or irregular cone), permitting its construction in unworked sheet material. As with other cases, the control curves between which the surface extends are not entirely independent. In this instance, the plane of the keel line and the transom have been fixed, together with the plan and elevation of the chine. The geometric construction consists simply in representing successive positions of the generators of a conoid with apex at A so that they define the position of the surface in the two views and enable the cross-section or station shapes to be deduced. Transverse and longitudinal sections (buttock lines) will both be curved lines. By making the generators parallel, the bottom could be made part of a cylindrical surface with the same chine but different keel line in elevation.

Fig. 4 will serve to illustrate how two arbitrary boundary curves in parallel planes can be spanned by either a developable or non-developable surface. In the left hand construction, the location of the line of contact of the tangent plane to the surface is determined by noting that such a plane cuts the boundary curve planes in parallel lines which must appear as such in the plan view and must also be tangential to the boundary curves. By trial, the points of tangency of these two lines can be found and the generating line to the surface located for the position considered. A series of such lines in two views defines the surface. In the right hand construction, the same boundary curves are joined by a series of lines between points equally spaced along each of the two curves. Here the surface so defined is not developable by the wrapping of a flat sheet but is similar in nature to the hyperboloid of Fig. 2.

In an aircraft wing, the boundary curves of the wing surface are usually the root and tip aerofoil sections located as shown exaggerated in Fig. 5. These shapes are determined from aerodynamical considerations. A washout angle is often applied between root and tip resulting in an end view of the type shown. The surface is then defined by a system of straight lines joining common per cent. lines and results in one which, in the strictest sense, is non-developable. However, it is usually in the leading edge or nose skin only that the departure from developability is significant. A given case could, of course, be tested by the method of Fig. 4, but aerodynamical considerations must here come before manufacturing difficulty.

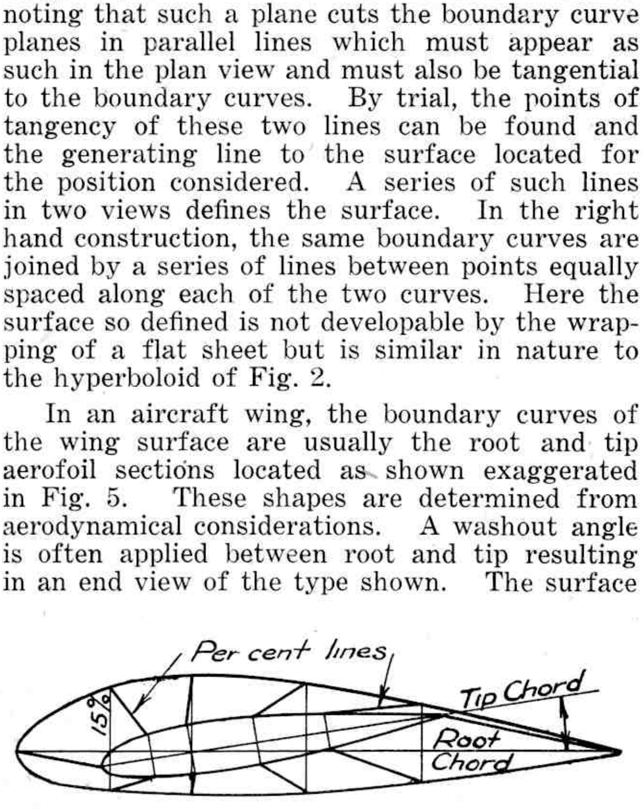


FIG. 5.

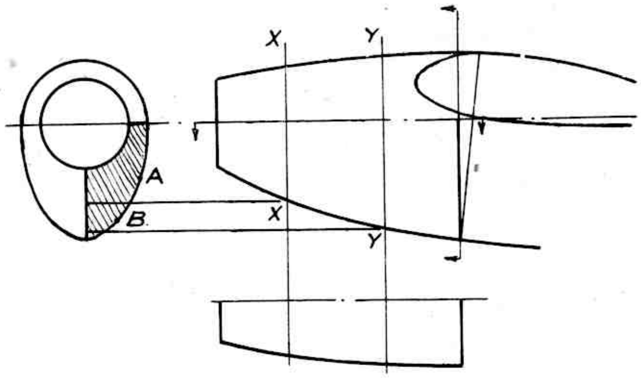


FIG 6

This last example has given an indication of the fact that many cases exist where the spherically curved surface must be accepted. Fig. 6 shows how the surface of an aircraft engine nacelle can be determined by means other than the conventional trial and error methods often employed for such a case. The boundary curves of the shaded surface in two transverse planes,

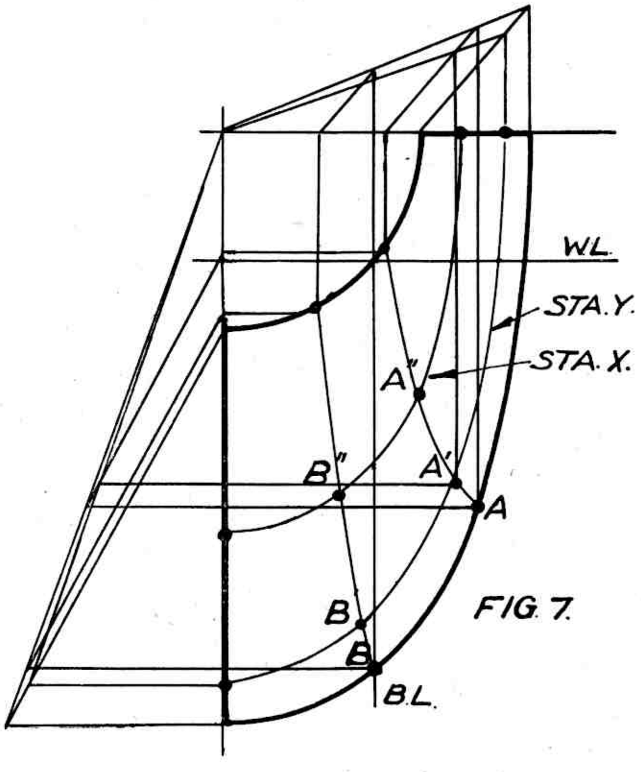


FIG. 7.

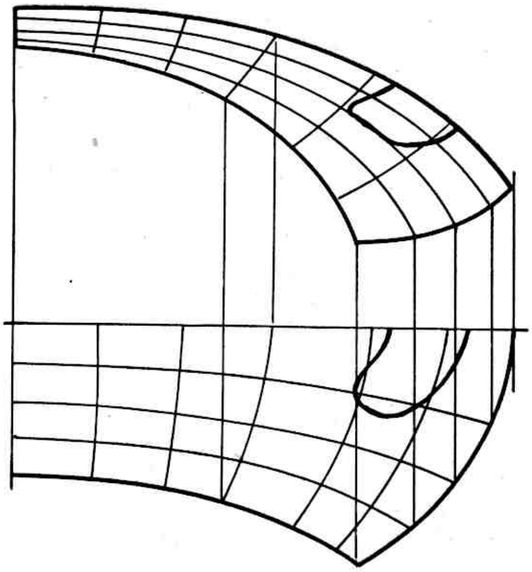


FIG. 8.

and in one or other of the vertical or horizontal centre-line planes, may be arbitrarily fixed or made to conform to some regular geometric forms. The construction for finding the outlines of stations XX and YY can be followed from Fig. 7, in which the intersections of these planes on the fixed longitudinal boundary curve are first located in this view. It is now necessary to determine the outline of sections XX and YY such that the surface which they define in conjunction with other similar sections is spherically curved and free from bumps, flats or unacceptable lines. Points A and B are selected in one of the transverse boundary curves and points A' and B' corresponding to them in section XX and A" and B" in section YY are then found by means of the proportioning scales depicted which make width and depth of corresponding points proportional to the overall width and depth of corresponding sections. The curves AA'A" and BB'B" are typical "radial development curves" and A'B' and A"B" are sections of the derived surface at stations XX and YY. Sections along BL on this surface will yield a conventional buttock line profile and section WL a water line profile. It will be found that, with accurate full size construction, all sections of this surface will be fair curves. The boundary curves control the form of the surface in conjunction with the method shown, but in this case the resulting surfaces are acceptable. From what has been said, it will be noted that the surface could have been made developable if the boundary curves in vertical and horizontal planes had been straight lines, but, as they are specified as curves, spherical curvature cannot be avoided.

Automobile panels demand a high standard of surface accuracy. Bumps and flats in the surface quickly show up in the highly polished finish as interrupted highlights. For this reason and the fact that boundary curves are arbitrary and more complex, as will be seen from the roof panel shown in Fig. 8, graphical constructions along the lines of the previous example and extensions of that approach are usual.

The layout of the outer surface of the units referred to is but a preliminary step in the complete process of producing the surface in physical form as a panel, and it is not the purpose of this article to enter upon a discussion of that process and the great variety of techniques and equipment used to impart the necessary curvature. It is hoped, however, that sufficient has been said to indicate that the geometry of curved surfaces has both technical and economic application wherever sheet metal is the major medium of construction.

THE GAS TURBINE

By B. J. BROOKS

IN the south-west corner of the Holden Mechanical Engineering Laboratory, an interesting machine is taking shape which is associated with a promising new development in power generation—the power gas turbine.

For centuries, man has been toying with the idea of a gas turbine. The first patent covering a gas turbine was granted in 1791 in England to one John Barber. The machine was intended to run on inflammable gases, and it is possible that the name "gas turbine" originated there. The machine was too crude to produce any net power, and it is doubtful if it was ever built. However, this invention makes it clear that the gas turbine is not a twentieth-century conception.

The last quarter of the 19th Century produced several gas turbines which were actually built and tried. However, no successful unit was evolved, chiefly due to the low compressor efficiencies and low turbine inlet temperatures. The low compressor efficiencies were due largely to a lack of knowledge of fluid flow characteristics. The low turbine inlet temperatures were made necessary by lack of suitable heat resistant materials. Sir Charles Parsons, the inventor of the reaction steam turbine, was unable to develop the axial flow compressor to a reasonable state of efficiency, despite his great genius and the resources at his disposal.

At the beginning of the twentieth century, attention was turned to the turbosupercharger. This is a device whereby the energy of the exhaust gases from an I.C. engine is utilised to compress air for the supercharging of the engine cylinders. The device is essentially a gas turbine with the engine cylinders taking the place of the normal combustion chamber and the turbine developing only enough power to drive the compressor. Much of the research done on turbosuperchargers has proved of value in the development of the true gas turbine.

The present form of the gas turbine is based on a "constant pressure" cycle in which the fuel is burnt at almost constant pressure in an "open" combustion chamber. On the Continent, however, a few "constant volume" or explosion gas turbines have been developed. The complication of the combustion chamber and cooling problems, however, dictate against the general adoption of this latter scheme.

The first large gas turbine placed in commercial use was in connection with the Houdry oil cracking process at the Marcus Hook refinery, near Philadelphia, U.S.A. The unit was built by the Swiss firm of Brown Boveri, who lead the world in the manufacture of power gas turbines. Since then numerous units have been installed for the same purpose and also in connection with the Velox steam generator. However, the gas turbine has advanced beyond the stage of being an auxiliary to commercial processes, and has become a prime mover of practical importance in the power generation field.

The largest gas turbine yet constructed is a 27,000 k.w. machine which has undergone trials in Switzerland, attaining a full load thermal efficiency of 34%. A 20,000 k.w. machine has also been constructed, whilst Escher-Wyss have proposed designs for a 100,000 k.w. 2-stage closed cycle unit, which has an estimated full load thermal efficiency of 40%.

The gas turbine consists essentially of three elements, namely, a compressor, a combustion chamber and a turbine. A line diagram of the arrangement is shown in Fig 1. This simple cycle is capable of considerable refinement, and intercoolers, heat exchangers and reheaters are also included in more complex cycles. A cycle which includes all possible elements is shown in Fig. II. The number of combinations that are possible is very large, and it is fortunate that the cycles can be analysed with relatively simple mathematics and their comparative worth assessed without constructing each one.

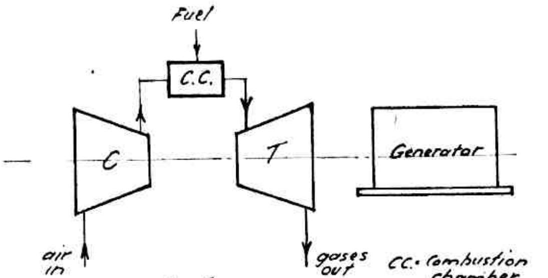


Fig. I.
Simple Gas Turbine

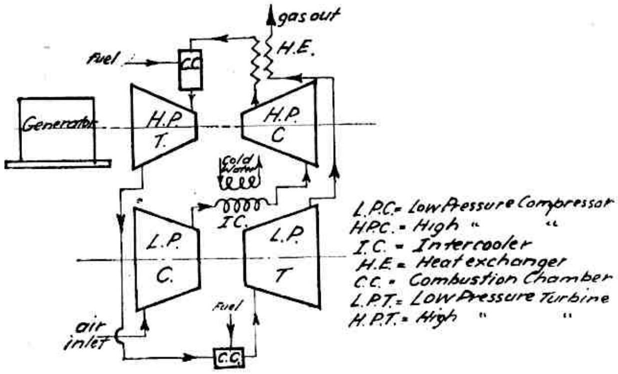


Fig II
Complex Gas Turbine

Basically, the operation of a gas turbine is as follows: Air is compressed and fed to a combustion chamber where it is heated by combustion with fuel, the resulting high temperature gases passing to a turbine where they do work in driving the wheel. The compressor is direct-coupled to the turbine and absorbs a considerable portion of the turbine output, the remaining power being the useful output. This simple cycle has an efficiency which is a function of the turbine inlet temperature, air inlet temperature and compression ratio in the compressor. In general, the efficiency increases with increasing turbine inlet temperature and decreasing compressor inlet temperature. This leads to the useful feature of the gas turbine, that its output is increased in the winter when it is most needed for heavier winter loads.

A turbine temperature of about 1500° F. is necessary to attain a thermal efficiency of 25% with the simple cycle. This temperature is too high for a long turbine life, and 1300° F. appears to be the present economic limit. It should be remembered that the blades are well above red-heat at this temperature.

The more complicated cycles must, of course, give greater efficiency to justify their greater initial cost and maintenance. A cycle involving several stages of compression, with water-cooling between each, heat exchanging whereby the heat of the exhaust gases is utilised to heat the air before combustion, and several stages of expansion with reheating between each, is capable of efficiencies above those of a modern steam power station.

Far less preparatory work is required in starting a gas turbine than is required for a comparable steam plant. The warming up period is slightly longer than is required for a steam turbine, but once operating temperature is reached full load can be applied immediately, an operation which is not possible with steam plant. In addition, the simple open cycle gas turbine is cheap and light and requires little space, and is independent of any water supply. These factors lead to cheap foundations and buildings, and permits the plant to be installed at any location. The simple open cycle gas turbine is therefore finding favor as a machine for carrying peak loads for short periods where the efficiency becomes secondary to convenience.

The gas turbine has found its greatest application, so far, in the field of aircraft propulsion. With development accelerated under the impetus of war, these engines have graduated to the propulsion of commercial aircraft. The jet type of gas turbine engine is by no means a Utopian device, but it has certain advantages that the propeller-driven aircraft does not possess. Firstly, it is capable of higher propulsion efficiency at high velocities, combined with lower specific weight and lack of vibration. It has fewer moving parts and a general mechanical simplicity. The ability of the jet engine to burn kerosene with its high calorific value and low inflammability is offset by the fact that the specific fuel consumption is twice that of the reciprocating engine. Also on the debit side is the liability of the compressor to "surge" at low air delivery, flow being completely stopped and probably combustion extinguished. This phenomenon has now largely been eliminated by research and design, but constituted a danger with early engines. The propeller engine of gas turbine or reciprocating type has approached the point where it uses most of its power to overcome its own drag at high velocities. The jet engine with a high output per sq. ft. of frontal area is not subject to this limitation, and is capable of propelling aircraft at supersonic velocities.

Although the aircraft gas turbine is an accomplished fact, gas turbines in marine and land propulsion are not so well advanced. As yet, no gas turbines have been commercially applied in marine work, although considerable research and development is at present taking place. The most notable unit has undergone tests in America at the factory of the Elliot Company. This develops 2,500 h.p., and consists of two compressors, and two turbines arranged on two shafts, the high pressure turbine driving the low pressure compressor and the low pressure turbine driving the propeller and the high pressure compressor. This arrangement gives good part-load efficiency as well as keeping temperature differences in the turbines to a minimum. Reversing of marine turbines is, of course, necessary for manoeuvring, and this complicates the machinery. The gas turbine, however, is of special interest to marine users, because of its ability to give high outputs with small space, thus leaving more space for cargo.

For land service, the gas turbine has already been proved as a prime mover for locomotives. A gas turbine locomotive, built by Brown Boveri and Company, was placed in service in 1941 on the Swiss Federal Railways, and has thousands of running hours to its credit. The unit develops 2,200 h.p., but its efficiency is lower than that of a diesel electric machine, due to the low turbine inlet temperature of 1,000°F. However, this was the first unit of its kind, and many improvements can now be introduced to make the gas turbine-electric locomotive a serious competitor with the diesel-electric. Since the war, the General Electric Company and the American Locomotive Company have produced and tested a locomotive gas turbine unit in America, and other units are under construction. British railway engineers have also realised the possibilities of the gas turbine, and several units are on order, both in Britain and America, for the National Railways. If the research on the burning of pulverised coal in gas turbines is successful, this type of locomotive will be far cheaper to run than reciprocating steam locomotives, steam turbine locomotives or diesel electric locomotives.

In the field of automobile propulsion, the gas turbine is indeed only at the dawn of its existence. Two different engines have been developed in Britain, one by the Rover Company and the other by the Centrax Company. The difficulty is to build a small unit and yet maintain a reasonable efficiency. The gas velocity from the turbine nozzles in a small unit is of the same magnitude as for a large turbine. For good efficiency the blade-speed ratio, i.e. the ratio of blade velocity to gas velocity in the turbine, must be kept constant. For small wheels, this necessitates extremely high angular velocities. Thus speeds of 55,000 revolutions per minute are encountered. Naturally, the balancing of these small wheels is very critical, and serious vibration will occur with the slightest imperfection. Fuel consumption is at present very high and, even though kerosene is used, the actual running cost is much greater than for an orthodox engine of comparable power. One big advantage of the gas turbine over the orthodox engine is its torque-speed characteristic. For automobile service, it is necessary to have the power turbine separate from the compressor turbine. This leads to a torque-speed curve for the power turbine with a maximum at zero speed falling off to zero at maximum speed. The power curve is a parabola over the same speed range. The torque characteristic does away with the necessity for gears, although provision must be made for reversing.

The experimental gas turbine under construction in the Mechanical Engineering Laboratory is quite a diminutive machine compared with most of the turbines previously cited. However, the project is quite ambitious when viewed in the light of the data which was at hand during the design of the unit and the obstacles which had to be overcome. The unit was designed by Mr. A. M. Bray as an honours project under the supervision of the staff of the Mechanical Engineering Department, and is expected to run before the end of this year.

The basis of the unit is a turbosupercharger from a Consolidated Liberator engine. The supercharger is made by the General Electric Company, who have done extensive research in this field. Five such superchargers, all type B22, have been obtained, and thus adequate spares and replacements are available.

The supercharger consists of a 12¼-in. diameter centrifugal compressor of the radial vane type cast from aluminium alloy, directly coupled to a 11-in. mean diameter turbine wheel of the single stage impulse type. The unit is controlled by an electronic system which protects it against over-speeding, over-heating, and excessive acceleration. The controller opens or closes a waste-gate which allows the hot gases to pass to atmosphere without expanding through the turbine. Normally the unit is governed to give only as much air as is required by the engine which it supercharges. The turbine wheel therefore develops only enough power to drive the compressor.

In using the turbosupercharger as a gas turbine, a combustion chamber must be used to heat the air and also some provision made to extract the useful work which is done. The useful work is the power developed by the turbine in excess of that required by the compressor, and will be a maximum when the waste-gate is closed. This work can be taken off in the form of compressed air from the compressor, or as electrical energy from a generator. The first method is used by the G.E.C. on a similar unit to that being built here. The second method is to be used here, the generator being used as a D.C. motor for starting purposes.

The layout is shown in Fig. III, and it will be seen that the power from the turbine unit passes to the generator via a Rolls Royce gear-box and a Chevrolet gear-box and clutch. Since speeds of 20,000 r.p.m. are to be encountered, a large reduction is necessary to allow the generator to run at 700 r.p.m., its design speed. The Rolls Royce gear-box is modified from the gear-drive of a Rolls Royce Merlin supercharger and has a fixed ratio of 8.5. The Chevrolet gear-box permits a single gear change during the starting of the turbine.

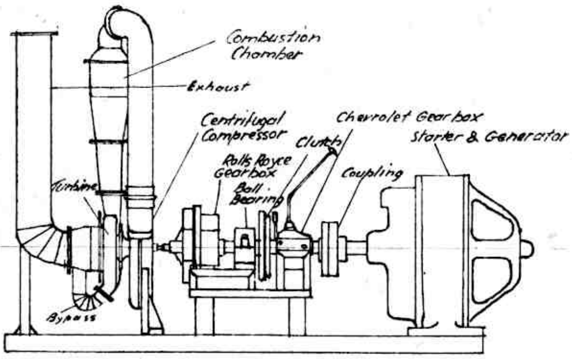


Fig III
Gas Turbine Layout

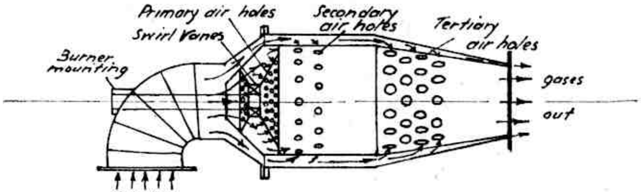


Fig IV
Combustion Chamber

The combustion chamber is of the straight-through type, modelled on the "flower-pot" design developed by Joseph Lucas Ltd. in connection with jet engines. This type is capable of a heat release rate of 4 x 10^6 B.Th.U./cub.ft./hr. and delivers gases to the turbine nozzle box at the rate of 4,500 cub.ft./min. Since the temperature in the combustion zone is between two and three thousand degrees, the gases must be diluted with cool air to reduce their temperature to 1,400° F. With these temperatures, it is necessary to use special material, since distortion and corrosion are very difficult to prevent. Also, since the inner and outer casing of the combustion chamber may have a temperature difference of 2,000° F., a large allowance is necessary for expansion. Fig. IV shows an elevation of the chamber. The flame tube is of Comsteel HR25/20 and the outer casing of mild steel. This outer casing is kept cool by the large flow of air in the annular space and can therefore be made from a lower grade material than the flame tube. The flame tube is axially located inside the outer casing by means of 3 bolts and a spring clip, this arrangement permitting large radial and axial expansion of the flame tube without distortion.

Ignition is achieved by means of an igniter mounted on the side of the combustion chamber. This igniter consists of a vane pump delivering air through a wick carburettor to a single hole directed into the combustion chamber. The carburettor gives a petrol-air mixture which is ignited by a hot coil plug until the igniter has warmed up. This petrol air mixture burns with a long flame which penetrates into the spray area of the combustion chamber, thus initiating combustion. Once ignition occurs, the combustion chamber will maintain the combustion without any outside agency, because the flow is such as to recirculate hot gas back into the unburnt, fuel air mixture.

The fuel to be burned is power kerosene, and this is fed into the chamber by means of a "simplex" swirl atomiser. This gives a cone of spray of very minute droplets, the apex angle of the cone being 85°. This type of nozzle has a flow characteristic in which the quantity delivered is proportional to the square root of the pressure. Thus for fuel flows varying widely, the variation of pressure may be from 100 p.s.i. to 700 p.s.i. in the fuel line. The simplicity of the nozzle, however, justifies any complication introduced by this pressure variation.

All auxiliaries of the gas turbine are driven by 24 volt D.C. motors obtained from Liberator aircraft. The electronic controller requires 115 volt 400 cycle power. Thus a special power supply is necessary, and a portable unit has been built up incorporating a 3-phase motor driving a D.C. generator and also a D.C. motor driving a 400 cycle inverter. Storage batteries are also included. This unit has proved very useful in laboratory work generally as well as in connection with the turbine.

Accurate predictions of performance are hard to make because of the many uncertain factors involved. Combustion chamber pressure loss has a large influence on output and as yet is an unknown factor, although it is inherently small in "straight through" type chambers. Ambient temperature also has an effect on performance, and obviously this can vary within wide limits. Gearing losses and stray pressure losses will also combine to reduce the output still further. One thing is, however, certain. The unit will not deliver any useful power below 18,000 r.p.m. and 1,200° F. turbine inlet temperature. At 20,000 r.p.m. and 1,400° F. inlet temperature, the unit shows a net turbine output of 40 h.p. These figures are based on component performance data supplied by the General Electric Company, and are probably on the conservative side.

In this particular experimental unit the turbine itself was originally designed as a supercharger, and was not required to deliver surplus power over and above that required by the compressor. The overall efficiency of the turbine wheel is of the order of 60%, whereas commercial gas turbines have wheel efficiencies of 90%. The compressor efficiency is only 70%, whereas commercial units have efficiencies of 80-85%. These figures effect the output tremendously, especially the turbine wheel efficiency, and are responsible for the high estimated specific fuel consumption and the low thermal efficiency.

As yet, only a limited amount of experimental work has been done in connection with the unit in the laboratory. Celluloid models of the combustion chamber were used to obtain typical flow patterns and desired distribution of primary, secondary and tertiary air for proper combustion and cooling, and equipment is almost complete for full scale testing for air flow in the actual chamber at atmospheric pressure. Spray nozzle and igniter experimental development has also been completed.

Testing of the compressor for performance curves is difficult. The power absorbed by the compressor rotor is about 200 h.p. at 20,000 r.p.m. and compression ratio 2.1. Since the largest available motor is 70 h.p., the compressor cannot be tested to anywhere near its full speed. The turbine itself cannot be used to supply power for compressor testing, since the compressor governs the turbine throughput and the turbine controls the compressor output, and in consequence only an "operating line" is obtained, giving the line where the compressor output and turbine swallowing power are the same.

The combustion field should be the most fruitful for local research, since tests and modifications are far easier than on turbine blading or compressors. The ultimate aim of this project is to develop a combustion system which will burn pulverised Leigh Creek coal. Naturally the system will be more complicated than that for liquid fuel burning, due to the difficulties of handling the coal and the removal of flyash after combustion. Such units have been built and tested, and have shown promise of success. It is hoped that a unit will be evolved which will assist in the utilisation of low grade coal in this country.

The possibilities of the gas turbine are great and there is much scope for useful experimental investigation in association with component design for the varied applications in transport and power generation.

WATER INJECTION IN I.C. ENGINES

By J. H. BAILS

ADDING water to the combustible mixture supplied to a spark ignition type of internal combustion engine is not a new idea. In 1913 Professor Bertram Hopkinson presented a paper to the Institute of Mechanical Engineers illustrating the improved performance brought about in a 50 h.p. coal gas engine by injecting water into the cylinder and removing the water jacket of the engine. He injected 2.4 lb. of water for each 1 lb. of coal gas.

During the years 1914 to 1926 very little interest was shown in water injection, but from then until the present time the subject has received considerable attention.

Detonation and the Effect of Water Injection

Detonation is the most important of all the factors limiting the compression ratio and therefore the power output from i.c. engines. Although it has been the subject of much discussion and practical research for many years, very little reliable and scientific knowledge has resulted. Many indirect causes and cures for detonation are known, but so far no complete explanation of the phenomenon has been made.

High octane fuels have been developed which do not detonate at quite such high compression ratios, but these are expensive.

Anti-detonates are available to be added to low grade fuels, but although reducing the tendency to knock, these additives introduce less serious effects, such as lead deposition and lowered total calorific value.

Water, which is easily obtained and cheap, has been found useful in preventing detonation. It acts firstly as a coolant, and secondly as a means of increasing the specific heat of the cylinder charge.

The following factors affecting detonation can be controlled to some extent by the introduction of water spray:

Factors inhibiting detonation	Effect of water
Slow rate of burning	Good
Rich homogeneous mixture	Good
Low charge temperature	Good
Low charge density	Bad
Low pressure rise	Bad
Low maximum temperature	Good
Large dilution by residuals	Bad

Although these factors inhibit detonation, they do not all improve engine performance.

Experiments have shown that the flame front travels at a greater speed over a hot surface (for example, the exhaust valve) than it does over a cool surface. Rapid burning is associated with high local pressure and temperature. The unburnt charge in the cylinder tends to explode under the influence of high pressure and temperature. If such an explosion does occur, the engine is said to detonate.

Water inducted or injected into the cylinder cools the charge by absorbing latent heat and by increasing the specific heat of the mixture. Also, it reduces the speed of flame travel by cooling the surfaces contacted by the wave front.

The cooling effect of the water helps to prevent the lighter fractions of the fuel from vaporising and separating from the fuel droplets. These lighter fractions will ignite readily when subjected to high temperature and pressure.

The immediate effect of introducing water (not in the form of steam) is to reduce the temperature and volume of the mixture. Thus the engine will be supplied with a cool charge of relatively high density. This larger charge tends to increase the maximum pressure reached on compression. Also, the charge dilution by residual gases is reduced.

Finally, the maximum temperature of the cylinder contents will be reduced, due to the cooling of the original charge, the slower rate of burning, and the increased specific heat of the mixture.

Methods of Injecting Water

Solid Injection.—In this case the water is injected directly into the combustion space by means of a small fixed-displacement pump. The type of spray produced and the distribution is of importance. The unit should be arranged to cool that part of the charge most remote from the spark plug, or that part which normally reaches the highest temperature.

Mist Injection.—This method is used in supercharged aircraft engines. A stream of water is injected into the inlet of the supercharger and the blading of the compressor breaks it up into a fine mist, in which condition it enters the engine cylinders.

Vapour Injection.—This system uses a small boiler heated by the exhaust gases and directs the steam produced into the inlet manifold.

Manifold Injection.—Here the water is sprayed into the manifold in a finely "atomised" form. Alternatively, the water is gravity fed into the low pressure area of the carburettor venturi, where it is partially atomised and mixed with the fuel and air.

Mist injection results in very good mixing with the intake air and resultant cooling. Solid injection has been used on a Citroen engine fitted with a modified cylinder head, and is described in the "Automobile Engineer," May, 1949. Vapour injection has been used in European countries during the past few years. Manifold injection has enjoyed some commercial success in Europe, and units for automobile engines are now on sale in Australia.

When to Use Water Injection

Although the addition of water to the charge produces certain very desirable results, its use is limited in practice to the following situations where it is desired to increase the output and fuel economy of an engine, by

1. Increasing the compression ratio;
2. Advancing the spark;
3. Increasing the air charge;
4. Preventing existing detonation;
5. Operating at speeds and loads which would normally overheat the engine;
6. Using a lower grade fuel than was intended for the engine.

Water injection is of little use when applied to an engine already giving the desired output and operating under normal running conditions.

Although commonly used in aircraft engines for temporary power boost, water injection is not at present generally used in automobile engines. The increasing demand for high compression ratio engines operating on low grade fuels might, in the future, force designers to turn to water injection as the only economical means of preventing detonation and ensuring smooth running.

Experimental work has been carried out on a single-cylinder spark ignition engine in the University Mechanical Engineering Laboratories which clearly indicates the effect of water injection on engine performance with petrol and kerosene fuels. The effect of exhaust gas dilution of the charge has also been investigated. Further work with a C.R.O. indicator now available to indicate clearly the onset of detonation should provide interesting and useful information on performance and on detonation control. The Ricardo variable-compression fuel research engine due to arrive this year from Britain should make possible a more scientific study of detonation and its control, the effects of charge dilutents on efficiency and other aspects of i.c. engine performance.

ELECTRICAL ENGINEERING DEPARTMENT

IT should not be interpreted from the absence of contributions that this department is idle. On the contrary, the hard working research team under Professor E. O. Willoughby is evidently too busy on their abstruse tasks to contribute anything. However, by persistent enquiry, it was discovered that the following subjects are under investigation:—

W. M. RICE.—Making very high frequency aerial investigations.

B. H. SMITH.—Designing and building a high voltage surge generator.

R. J. POOLE.—Constructing aerial measuring and display equipment.

S. D. KANEFF.—Investigating power system simulating systems.

S. G. F. ROSS.—Investigating servo system analysers.

A BRIEF REPORT ON SOCIETY ACTIVITIES FOR 1949-50

ANNUAL DINNER

This was attended by 60 members of Staff and Faculty immediately after exams. The Staff were subjected to an examination but were found to be sadly below standard.

The evening ended with the keg.

ORIENTATION WEEK

Freshers were invited to an informal evening in the George Murray, in order to meet the Staff and have their subscriptions extracted. Supper was provided.

INITIATIONS

These were spread over a week and were intended to improve the freshers' knowledge of army procedure, shoe-cleaning, interior decorating, and street-cleaning. Needless to say, the "Greasers" won the annual tug of war against the "Greasers." The week ended with a barbecue at Brownhill Creek, when the freshers showed that there was little they did not know about correct procedure on such occasions.

ENGINEERS' BALL

The 1950 Ball was almost unique in that a profit of almost £40 was made out of about 150 couples. Rod Linklater worked hard as convener, and we extend our thanks to the hard-working Women's Committee.

CHOIR

This was the baby of Geoff Canaway and Don Bennier, who undertook the virtually hopeless task of training an Engineers' Choir. However, they definitely got the better of the job, and the result was the "Male Quire," which performed successfully at the Ball, Dinner-Dance, and other Varsity functions.

DINNER-DANCE

Staff and students were given an opportunity to bring their "one and only" or "one of many" along to see what an Engineering dinner was like. There was a marked improvement in both attendance and behaviour over previous dinners. Whether this was an advantage or not is still doubtful. A licence until 11 p.m. was obtained, giving a most successful evening in John Martin's Dining Hall.

PROCESSION

The Society had nothing to do with the Procession this year, apart from paying the bills run up by some the less apathetic Engineers.

FILMS

Films, sponsored by the A.U.E.S. and presented by the A.U.E.S. Film Sub-Committee, were shown once per fortnight during the dinner hour. Mostly documentary films. However, it is hoped that a full length feature may be shown one evening.

TALKS

Talks by Mr. Benjaminson and Mr. Wright on "Eng. Education in the States" and "Experiences in Japanese Prison Camps" respectively, were given during the year.

CURRICULUM

Two very heated meetings were held, whereat everyone had a chance to stand up and shout his idea of what the course should be like, with particular regard to third year.

All motions passed at these meetings were summarised by the executive and presented in the form of a report to a joint Staff and student meeting. Criticism by the Staff was invited.

No satisfactory conclusion has yet been reached.

CONCLUSION

On the whole, the year has been fairly successful, but the Society needs more members, more individual interest, and more meetings.

B. H. SMITH,
Secretary.

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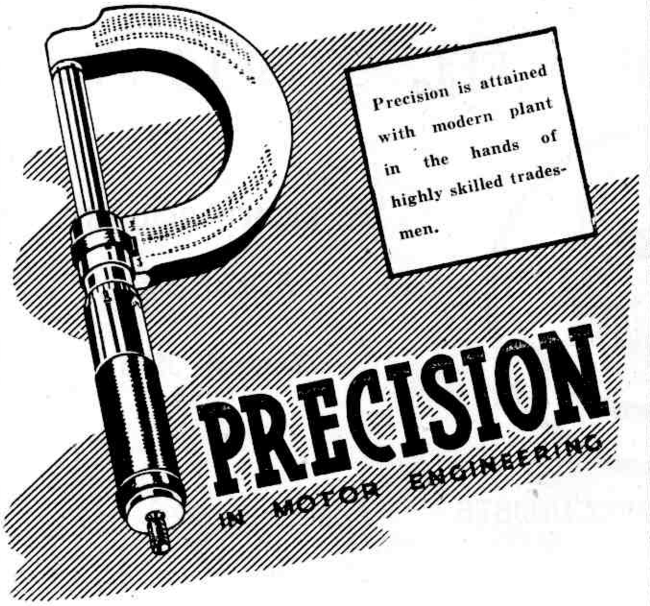

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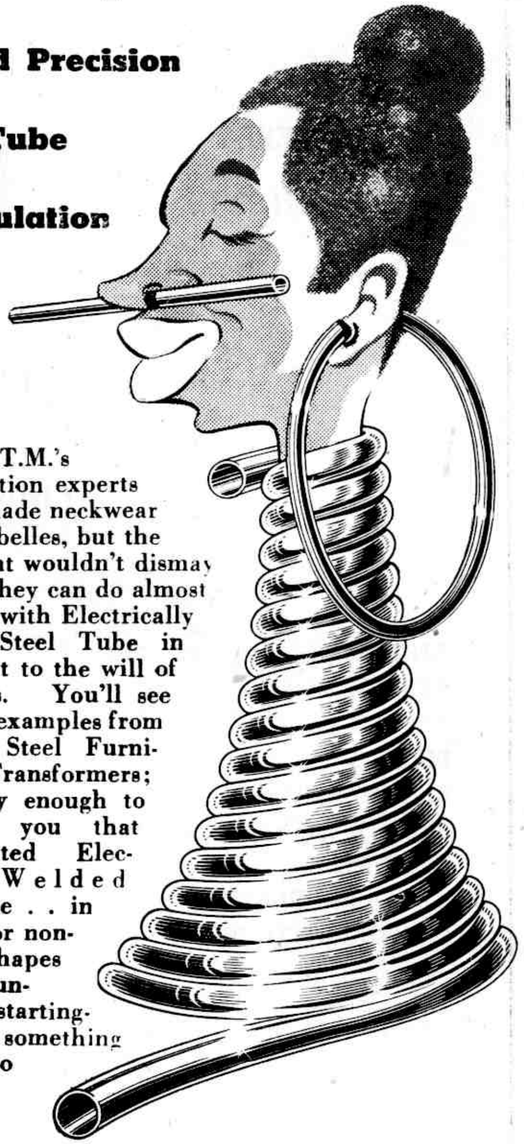

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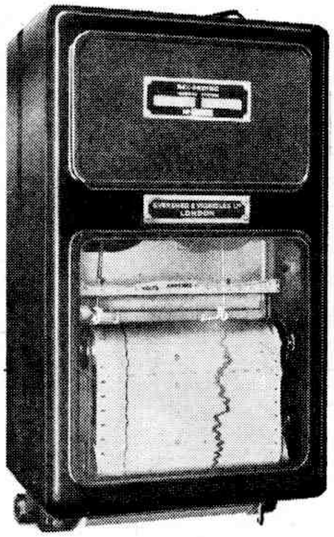

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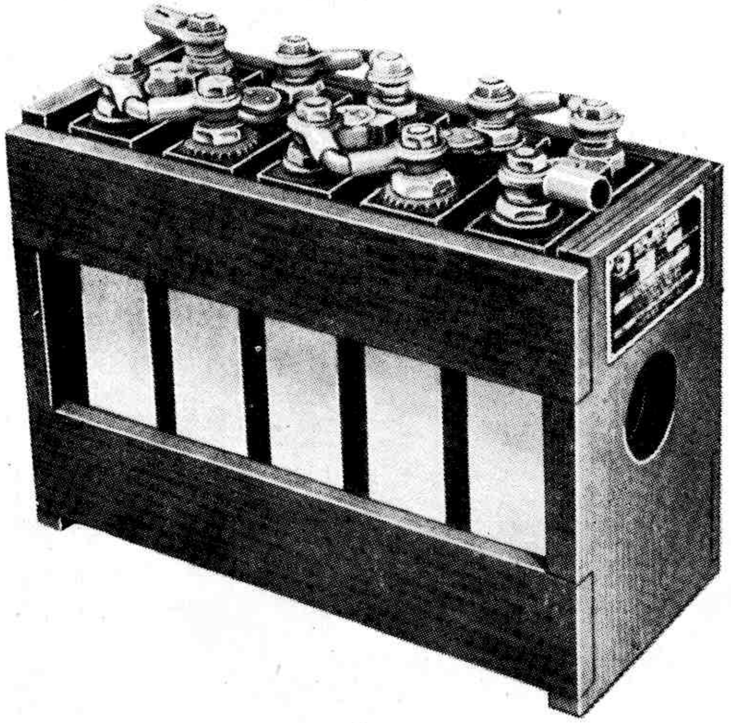

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for . . .

- MARINE WORK
- SWITCH TRIPPING
- SWITCH CLOSING
- LABORATORY RESEARCH APPARATUS
- EMERGENCY LIGHTING

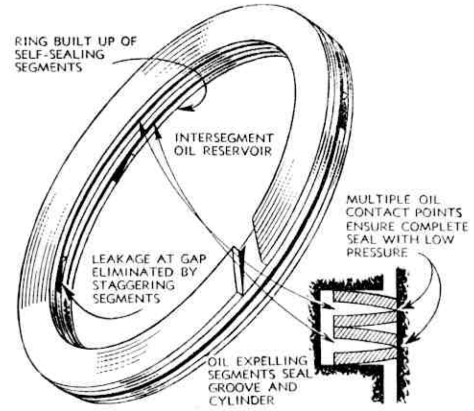
Contains neither lead nor acid, thus sulphation is impossible ▮ Is built to stand violent vibration and hard usage ▮ The steel plates cannot buckle, grow, or shed active material ▮ The steel containers cannot crack ▮ Produces no corrosive gases and there is no corrosion of terminals ▮ Has very small volume and is light in weight ▮ Is not injured by over-charging ▮ Is not injured by rapid discharge or short-circuiting.

Will stand for long periods charged or discharged without deteriorating in any way ▮ Will hold a charge for very long periods ▮ Is the simplest accumulator to operate ▮ Is unharmed by exposure to the lowest temperatures ▮ Has very low maintenance cost and, in consequence, it is the cheapest accumulator in the world when one considers its length of life.

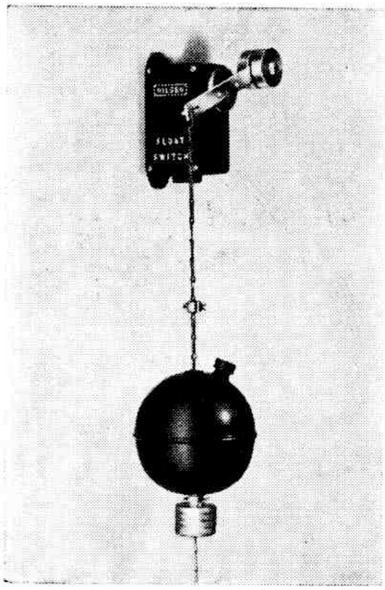
HANNAN BROS. LTD.

63 FRANKLIN STREET, ADELAIDE

'Phone: Central 6044


RING BUILT UP OF SELF-SEALING SEGMENTS
INTERSEGMENT OIL RESERVOIR
MULTIPLE OIL CONTACT POINTS ENSURE COMPLETE SEAL WITH LOW PRESSURE
LEAKAGE AT GAP ELIMINATED BY STAGGERING SEGMENTS
OIL EXPELLING SEGMENTS SEAL GROOVE AND CYLINDER

NILSEN SWITCH GEAR



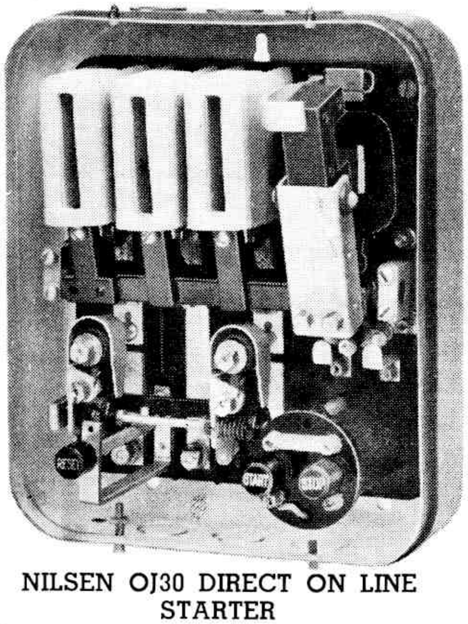
NILSEN FLOAT SWITCH

The Nilsen new precision snap acting float switch is designed to control high and low water levels in conjunction with motor driven pumps.

Nilsen Quality Switch Gear

IS AVAILABLE FOR EVERY INDUSTRIAL APPLICATION.

Illustrated are two of the "stock" items available from the range of NILSEN SWITCH GEAR.



NILSEN OJ30 DIRECT ON LINE STARTER

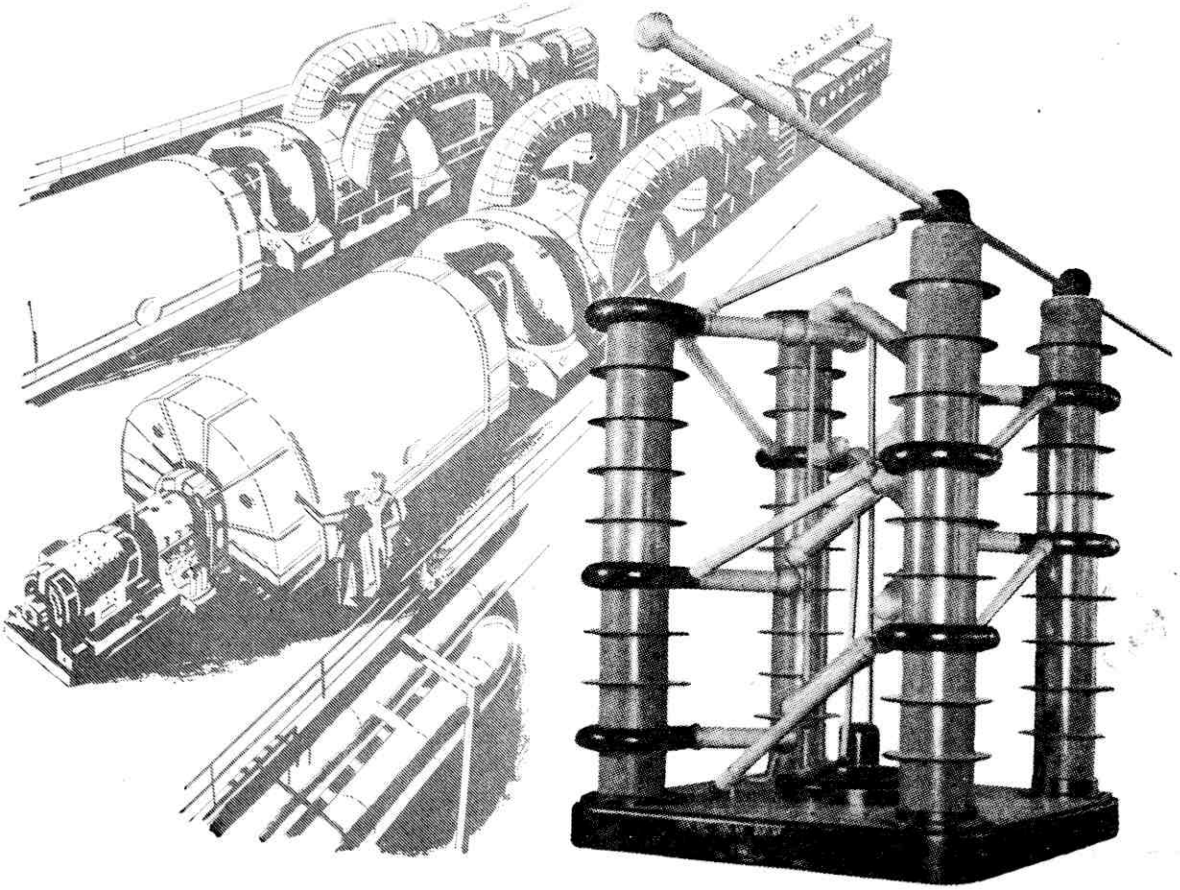
The Nilsen OJ30 Magnetic Contactor Starter is designed for use with squirrel cage motors from $\frac{1}{2}$ to 10 H.P. rating. Available with integral or remote control, in both indoor totally enclosed or outdoor weatherproof units.

All types feature "Automatic" Ambient Temperature Controlled Thermal overload relay.

For Further Details Consult . . .

OLIVER J. NILSEN & Co., Ltd.

64 GAWLER PLACE, ADELAIDE - Phone C. 4881



SURVEY a future with the steel industry

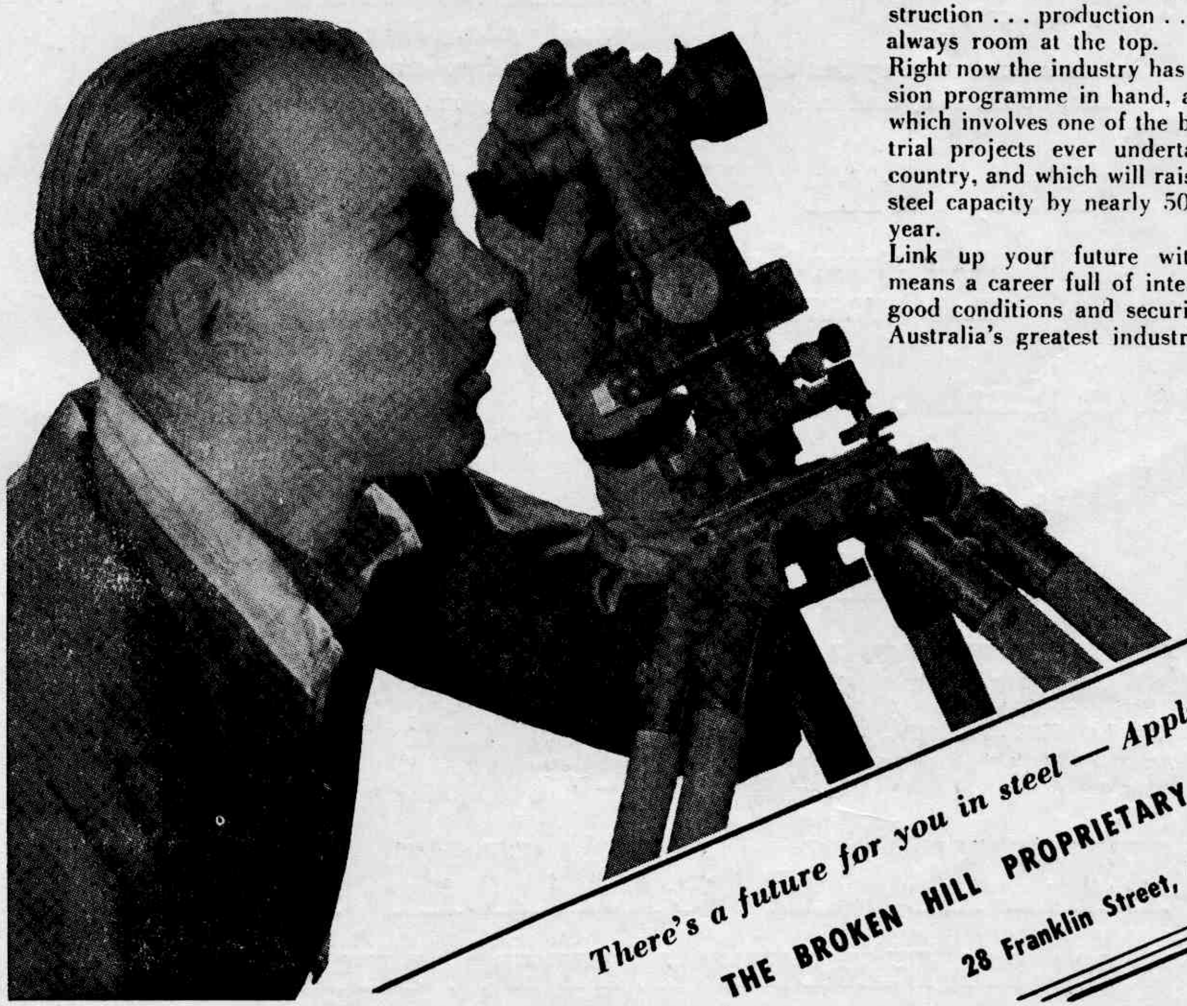
Its expansion means bigger opportunities for YOU!

THE steel industry is going ahead. Its progress can be your progress too. The industry needs graduates in all branches of engineering for appointment as cadets. These cadetships provide you with two years' experience of steel plant practice and the operations of the industry generally as a preparation for promotion to the more senior jobs.

Steel is Australia's largest and most important secondary industry. Its wide-ranging operations — iron and steel production, coal mining, iron ore winning and shipbuilding — provide a wealth of opportunity for the keen and ambitious man . . . in design . . . construction . . . production . . . and there's always room at the top.

Right now the industry has a big expansion programme in hand, a programme which involves one of the biggest industrial projects ever undertaken in this country, and which will raise Australia's steel capacity by nearly 500,000 tons a year.

Link up your future with steel. It means a career full of interest, plus the good conditions and security of one of Australia's greatest industries.



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The Chemist Says 5/-

A man may be worth £2,000 a year in his business capacity, but this capacity is dependent upon a physical body worth about 5/-. Chemically speaking, it contains 65% oxygen, 18% carbon, 10% hydrogen, 3% nitrogen, 2% calcium, 1% phosphorus, and 1% copper, zinc and what not. It is a wonderful machine, of course, with spare parts, viz., a spare eye, a spare ear, several spare fingers, and so on, which is partly why he survives.

Yet, it is extraordinary that this soft, brittle, vulnerable, and in so many cases impaired, human body, which has to be kept warm by clothing, heated dwellings and other artificial means, which is liable to innumerable diseases and disabilities and easily broken by a comparative slight impact—it is extraordinary that it can be preserved in average instances for half a century or more. Notwithstanding all perils of swift traffic and unnatural town-dwelling conditions, we as a community are actually getting older, more intellectual, but—if we consider the state of the world in general—none the wiser.

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Their strength remains the same
Their WORTH increases as they're used.

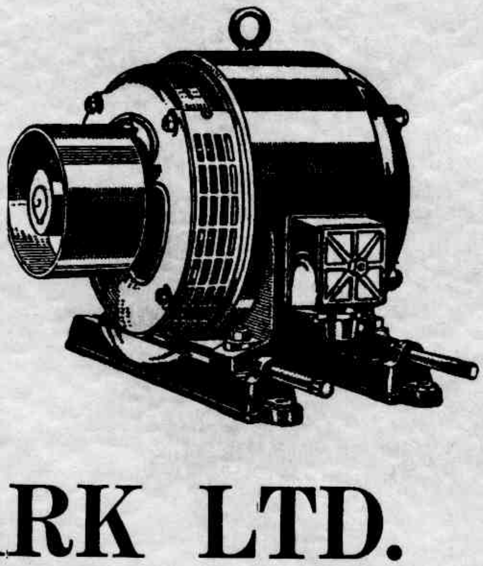
Large or Small . . .

There's a

"BROOK"

A.C. ELECTRIC MOTOR

To Suit Your Requirements



ELLIS & CLARK LTD.

204 - 214 FLINDERS STREET, ADELAIDE