NOTES ON STEAM-ELECTRIC POWER ENGINEERING WITH SPECIAL REFERENCE TO THE CIVIL ENGINEER

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✳

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BEIT FELLOW FOR THE TWO RHODESIAS

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“*Crafty men contemn studies, simple men admire them, and wise men use them.*”

FRANCIS BACON (LORD VERULAM)

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Note : All photographs apply to Littlebrook " A " Station.

PREFACE

These notes were compiled during the period when I acted as Resident Engineer for Sir Alexander Gibb & Partners, Consulting Engineers, who were responsible for the design and supervision of construction of the Civil Engineering works relating to the Littlebrook "A" Power Station, Dartford, Kent (Kent Electric Power Company). Messrs. Merz & McLellan were the Electrical and Mechanical Co-Consulting Engineers.

The opinions expressed in this work are entirely my own, and the Consulting Engineers can in no way be held responsible for them.

Many references have been made to publications dealing with these or related subjects, and acknowledgments have been made to the authors concerned in the Bibliography attached, and throughout the text Bibliography references have been indicated in brackets.

I wish to record my especial indebtedness and thanks to the following authorities and persons :—

Sir Alexander Gibb & Partners, and in particular to Sir Leopold Halliday Savile, K.C.B., M.I.C.E., M.I.E.Aust., and to Mr. F. W. Matthews, M.I.C.E., for the special facilities granted to undertake practical experiments, and for their encouragement to complete this work.

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The Beit Railway Trustees, whose Fellowship funds made it possible to undertake these studies, and in particular to Mr. H. H. Hitchcock (Secretary to the Trust in Great Britain) and to Mr. T. H. Cooke (Secretary in Rhodesia), whose unfailing interest and encouragement is so valued by all Beit Fellows and Scholars.

The late Professor A. E. Snape, M.Sc., M.I.C.E., M.I.T.P., Professor of Civil Engineering, University of Cape Town, who was responsible for adjudicating this thesis.

Mr. F. M. Atkins, F.R.G.S., for his valuable advice and assistance in preparing the diagrams and drawings for printing.

I hope that these notes may be of some assistance to young engineers who are interested in this section of our profession, and that the work may help to stimulate new lines of thought and approach to the problems involved.

Henry Olivier

" Grey Stones,"
Oathall Avenue,
Haywards Heath, Sussex.
12th January, 1947.

NOTES ON STEAM-ELECTRIC POWER ENGINEERING WITH SPECIAL REFERENCE TO THE CIVIL ENGINEER

INTRODUCTION

The advent of the large super power station opened up a new field of endeavour for the engineer, and in particular for the civil engineer. When associated with a project of this nature, he is tested not only for his knowledge of the diverse problems associated with his own branch of the profession, e.g. heavy foundation work, piling, cofferdam and compressed air work, tunnelling, construction of jetties, chimneys, etc., roadmaking, layout of sewers and drains and railways, etc., etc., but also for his skill as a collaborator with his colleagues, the mechanical and electrical engineers, and his capacity for co-ordinating and timing of works. Moreover, he is confronted with a strong and complex economic motive, the characteristics of which are such that he is often required to modify his own conceptions of standard practice in order to conform with the requirements of high economy. At each stage his work is liable to scrutiny with a view to ascertaining that the results will conform with the requirements of " Continuity of Service "—a phrase grown up around and associated with power engineering—and his whole economic outlook must at all times be orientated in such a manner as to enclose the fourth dimension, the time element, within his traverse of considerations. Here, as in no other branch in the profession, he becomes conscious of the fact that he is concerned with man hours, not only men ; plant hours, not purely plant ; pound years, not only pounds sterling ; kilowatt hours, not only kilowatts.

Many excellent books and papers have been published dealing with diverse selected principles and problems connected with power engineering. Rarely, however, have these problems been scrutinised from the standpoint of the civil engineer. An examination of published data shows that the investment costs allocable to civil engineering amount to anything between one-quarter and two-thirds of the total costs. As it is by no means conceded that saturation point has been reached as regards economic design and construction of such works, it follows that one of the main roads towards achievement of greater economy springs from the better appreciation by the civil engineer of his function in this alliance of engineers, and his insistence on having a say in design problems commensurate with the amount of investment allocable to his branch of the work.

It cannot be overstressed that there does not exist (and possibly never will exist) a formula on " How to build a power station." Each particular station, for a given function, of given capacity and on a particular site, requires anew the examination of all the complex and pertinent principles and problems ; the proper proportioning and use of men, plant, money and materials, which process embodies the very essence of real engineering as opposed to mere mathematical precision based on assumption, and academic knowledge of materials.

There are, of course, certain fundamental principles common to all such schemes, and it is often surprising to note how little, if at all, some of those have changed in the short but very expansive life of this form of engineering.

Before examining the main fundamental principles in closer detail it may be well to cast a brief glance over the main events in the history of power engineering.

CHAPTER I

BRIEF OUTLINE OF HISTORY

The reciprocating steam engine was born in 1769 when James Watt patented the results of his experiments. Progress was along the lines of increased pressure and temperature for the steam. Thus, by 1872 marine engines had become of the compound type with boiler pressures up to 60 lb per sq. in. By 1881 the mean pressures had risen to 75 lb per sq. in., and by 1891 to 160 lb per sq. in. In 1894 there occurred a momentous event ; the steam turbine, for which we are indebted to the Hon. Sir Charles Parsons, was born, and underwent its trials in the s.s. *Turbinia* (1). From this time dates the steam turbo-alternator as we know it, and the subsequent progress, made during 50 years, as regards increased efficiency and output of prime movers, etc., can be seen from Figs. 1 and 2.

Fig. 1 shows very clearly the progress made in the reduction of fuel consumption per unit generated, and also brings out the fact that since 1905 there is not much to choose between the rates of development in Great Britain and America (1) and (2). The curves also show the slowing up of the rate of improvement in later years, which has led many people to believe that saturation point has been reached as regards economic design. This question will be examined in closer detail later in the work. Fig. 2 shows the " Progress in utilisation of Steam Energy, 1890 to 1935 " (1).

Together with the above mentioned improvements in machines went the rapid expansion of power generation and supply. In Great Britain, the first Act of Parliament dealing with the supply of electricity was passed in 1882 (1), but it was only in 1898 that electricity became available for power purposes. Yet by 1916, the Coal Conservation Committee, enquiring into the question of electricity supply found that the public supply rested in over 600 Authorities in as many districts, all operating at varying degrees of efficiency and at 15 to 20 different frequencies, with about 70 different prices for supply (1) and (2). The Committee made many recommendations regarding a comprehensive scheme for Great Britain. As a result there was born the 132 kV " Grid " system.

The rapid expansion of public electricity supply in Great Britain in the post (1914-18) war period up to the time when the Grid came into operation is shown in Table 1 (1).

Capital Costs

Up to the end of 1932-33 the total capital expenditure of the Central Electricity Board and its associated undertakings had been £436 million, or (say) 8·5d. per unit generated and 10·3d. per unit actually sold.

TABLE I

OFFICIAL FIGURES FOR AUTHORISED ELECTRICITY UNDERTAKINGS IN GREAT BRITAIN (1)

YEAR	Million Units (kW hours) of Electricity					Fuel consumed Million	
	Generated	Sold For					
		Domestic Purposes	Public Lighting	Traction	Power	Tons Coal	Cu. ft. Gas
1921-22	3,890	607	51	359	2,105	5·36	406
1922-23	4,541	711	60	386	2,605	5·48	2,210
1923-24	5,289	892	70	417	3,089	6·17	2,591
1924-25	6,022	1,038	81	447	3,532	6·06	1,758
1925-26	6,619	1,244	90	512	3,760	7·00	2,547
1926-27	6,992	1,444	96	561	3,767	7·00	1,093
1927-28	8,451	1,708	114	643	4,538	7·96	2,522
1928-29	9,324	2,036	128	710	4,926	8·23	2,943
1929-30	10,401	2,344	144	770	5,408	8·88	2,771
1930-31	10,947	2,744	164	794	5,371	8·09	1,904
1931-32	11,533	3,072	183	811	5,435	8·74	2,450
1932-33	12,347	3,468	198	850	5,693	9·07	2,583

Generating Costs

In 1932-3 the average generating costs (exclusive of capital charges) for all the authorised electricity undertakings were 0·214d. per unit generated, of which 0·137d. represented fuel. And if 10 per cent interest and depreciation in respect of the approximately £145 million capital chargeable to generation were added thereto, the total generating costs would become 0·495d. per unit.

Distribution Costs

Of the 12,347 million units generated in 1932-33 only 10,209 million units reached the consumer (82·7 per cent), the rest being either used on the power stations or lost during transmission. And if only 7·5 per cent be allowed for interest and depreciation on the £291 million capital sunk in distribution plant, the capital charges for distribution would work out at about 0·51d. per unit actually supplied. The total revenue averaged 1·44d. per unit sold.

In 1932-33 there were altogether 451 generating stations (243 owned by public authorities and 208 by companies) with a total generating capacity of 7,365,869 kW ; of these, 14 had a capacity of 100,000 kW and over, 33 were between 50,000 and 100,000 kW, and 69 of between 20,000 and 50,000 kW (1).

In 1932 these stations were operating independently, but after that year a large number of " selected " stations began to operate under the control of the Central Electricity Board. The fundamental principle on which the 1926 Act was based, and the Grid established, was " The creation of a system of inter-connecting transmission lines between generating

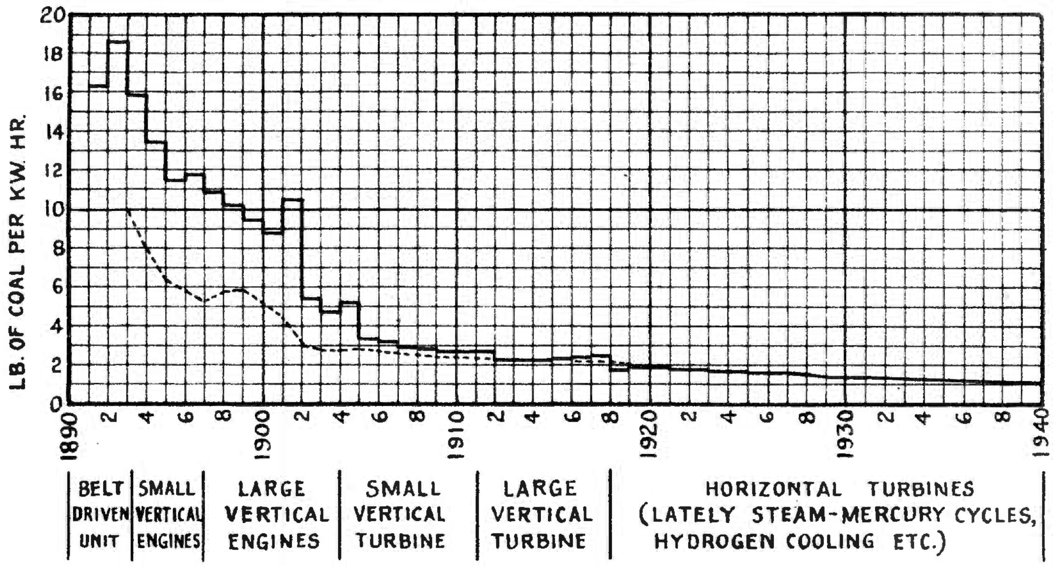


FIG. 1

PROGRESS MADE IN BRITAIN AND AMERICA IN REDUCING COAL CONSUMPTION PER KW. HR. 1890 - 1940

-------- AVERAGE PERFORMANCE FOR AMERICAN STATIONS. FROM........(2)

——— DATA FOR MOST EFFICIENT POWER STATION. NORTH EAST ELECTRIC Cº (BRITAIN). FROM.........(1)

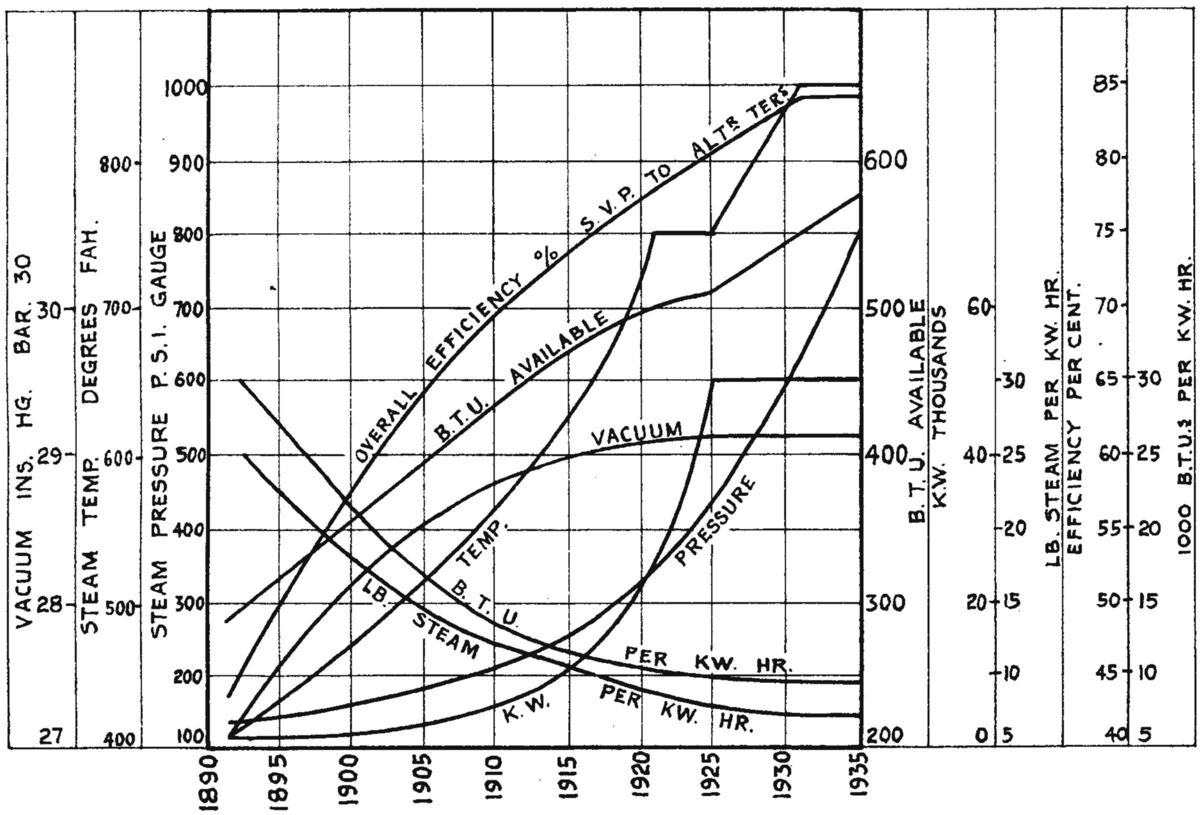


FIG. 2

PROGRESS IN UTILISATION OF STEAM ENERGY, 1890-1935

FROM........(1)

stations placed as near as practicable to the load centre, and extended, or increased in number, as and when required. The Grid thus differs essentially from most high voltage transmission systems abroad in that it is not intended or designed for the bulk transmission of large supplies of electricity from generating stations remote from the load centres." (3).

By 1938 there were 171 generating stations under the direction of the Board, and the following table, taken from the " Eleventh Annual Report of the Central Electricity Board " (3) shows how these stations were operated during 1938 :—

TABLE 2

Number of Stations	*Hours run*
30	8,760 (Full year)
21	Between 6,600 and 8,760
68	Between 2,400 and 6,600
43	Less than 2,400
9	None. (Shut down)
171 Total	

Fourteen of the most economical stations supplied 50 per cent of the units generated for the Board.

Fig. 3 (3) illustrates very clearly how, between 1932 and 1938, the approximate reserve capacity, which had steadily increased up to 1932, was cut down until in 1938 reserve capacity amounted to approximately 11 per cent of installed capacity. According to the Eleventh Report of the Board, this resulted in a total capital saving of £28 million—or nearly three-quarters of the capital expenditure on the construction of the Grid and its reinforcements and extensions to that date.

Fig. 4 (3) shows how the average costs of production per unit sent out from all the stations operating under the control of the Board were steadily reduced from 1932 onwards. Fig. 5 (3) shows the more rapid downward trend of production costs since Grid operation, due to advance in technique. When we also take into account the fact that the average price of coal in 1938 (for the above stations) was approximately 20s. 3d. as compared with 14s. 9d. in 1935, and that fuel comprised more than 25 per cent of the total cost of production, the major economies achieved become even more striking.

Other interesting facts from this report are that in 1938, for the first time since 1932, the rate of increase in generation fell below 10 per cent per annum, and that for that year total generation for Great Britain was estimated at 24,376,024,000 units, with an installed capacity of 8,264,160 kW. (Estimated population : 46,007,610.)

According to Himus and Bone (1) the economy of large generating stations may be ascribed to :—

(1) The employment of much larger generating units with higher boiler pressures and with more complicated but more efficient steam cycles than are possible with any combination of small sets ; and

(2) The better load factor that can be assumed when the area supplied by a generating station is sufficiently large.

It is generally conceded that the co-ordination of power generating facilities by interconnection has proved universally economical wherever attempted, and has been effective in reducing the cost of power, the economies being created by one or both of the following factors (10) :—

(1) Avoided investment in production facilities owing to the improvement of load factor by the merging of individual load curves resulting in a less " peaky " total load curve. Thus reserve capacity may be reduced as shown in Fig. 3. Moreover, such a system allows the extension programme to be staggered to suit regional needs.

(2) Reduction in production expenses.

Dr. Klingenberg in " Large Electric Power Stations " (4) advocated, even before the 1914-18 war, " the formation of large electrical undertakings for the erection of power stations on a very large scale and in the best situations." In the spring of 1927 there came into operation one of the forerunners of super power stations, the Klingenberg Super Station. (Berlin Electricity Works.)

As regards the trend in America, Lovell (2) gives, for generator sizes, the following :—

1906-08	..	8,000 kW to 14,000 kW
1908-11	..	14,000 kW to 20,000 kW
1911-15	..	20,000 kW to 35,000 kW
1915-17	..	35,000 kW to 45,000 kW
1917-24	..	45,000 kW to 60,000 kW

From 1925 the generators were sometimes developed in double and even triple shaft machines as well as in single shaft units, the increasing sizes in the last classification being indicated by 90,000 kW in 1928, 160,000 kW in 1929, and 165,000 kW in 1934. (Richmond Station, Philadelphia Electric Company.) The improved designs utilised higher blade speeds which result in great saving of weight per kilowatt, which, apart from reducing the size of turbines per kilowatt, saves building space and foundations. See Figs. 6 and 7. By about 1937, metallurgical researches had produced steels capable of taking steam at 1,250 lb per sq. in. and 925°F. on a regenerative cycle without reheat. Large generators were stepped up to 3,600 r.p.m. The new era of super-position or cross-compounding commenced about this time. Hydrogen cooling was first applied to commercial generators in 1937, thereby materially assisting the stepping up of blade speeds in larger units.

The trend of American performance is further illustrated by Fig. 8, which shows the improvements in heat rejected to cooling water, and in heat lost in flue gases.

Improvements to boiler plant have developed parallel with the above in the efforts to reduce overall fuel consumption, which, even to-day forms a large item of production expense.

In Europe, in 1933, the Trebovice Station in Czechoslovakia began operation with steam at 1,849 lb per sq. in. and 932°F. supplied to two 21,000 kW Skoda three-cylinder turbines operating on a reheat, regenerative cycle, utilising three Loeffler boilers evaporating, each, 150,000 lb per hour and fired with pulverised coal (2).

It is in the light of such a record of progress and search for efficiency that the civil engineer pauses to reflect on the manner and the amount of his contribution towards the reduction of capital and operating costs. In his case no simple curve can be drawn showing how progressive and continuous economies have steadily contributed towards the downward trend of production costs. Some of the reasons as to why it is difficult to make such assessments for civil engineers may be found in the following :—

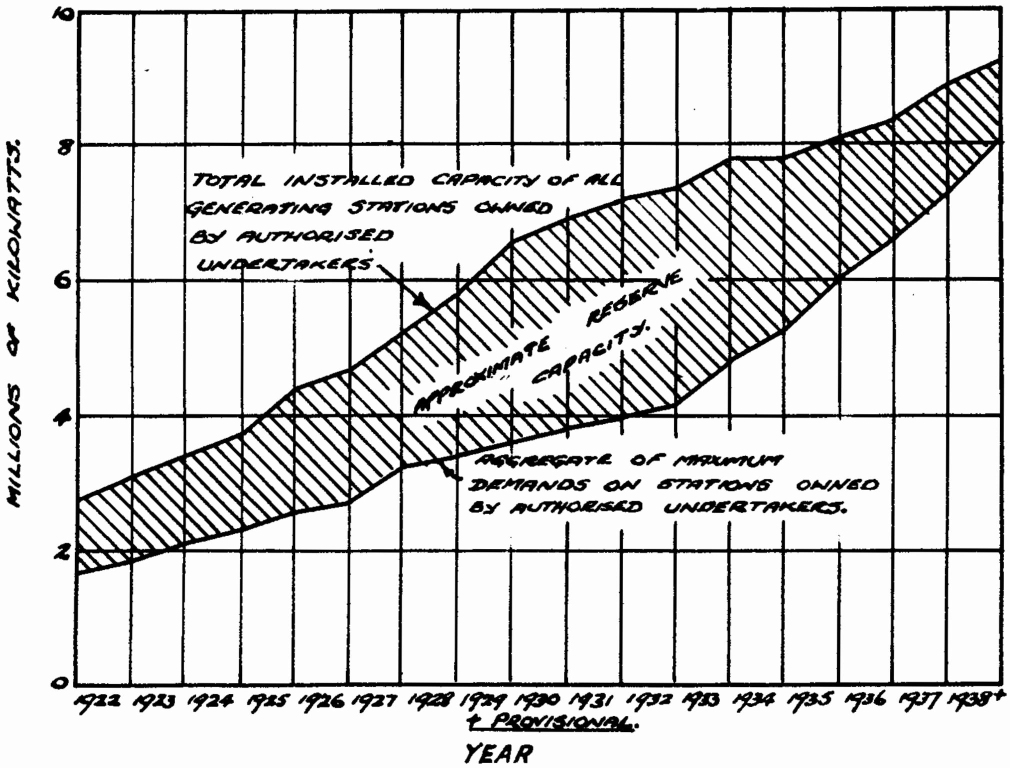


FIG. 3

CENTRAL ELECTRICITY BOARD DATA SHOWING RESERVE CAPACITY BETWEEN 1922 AND 1938 FOR STATIONS OWNED BY AUTHORIZED UNDERTAKINGS

FROM......(3)

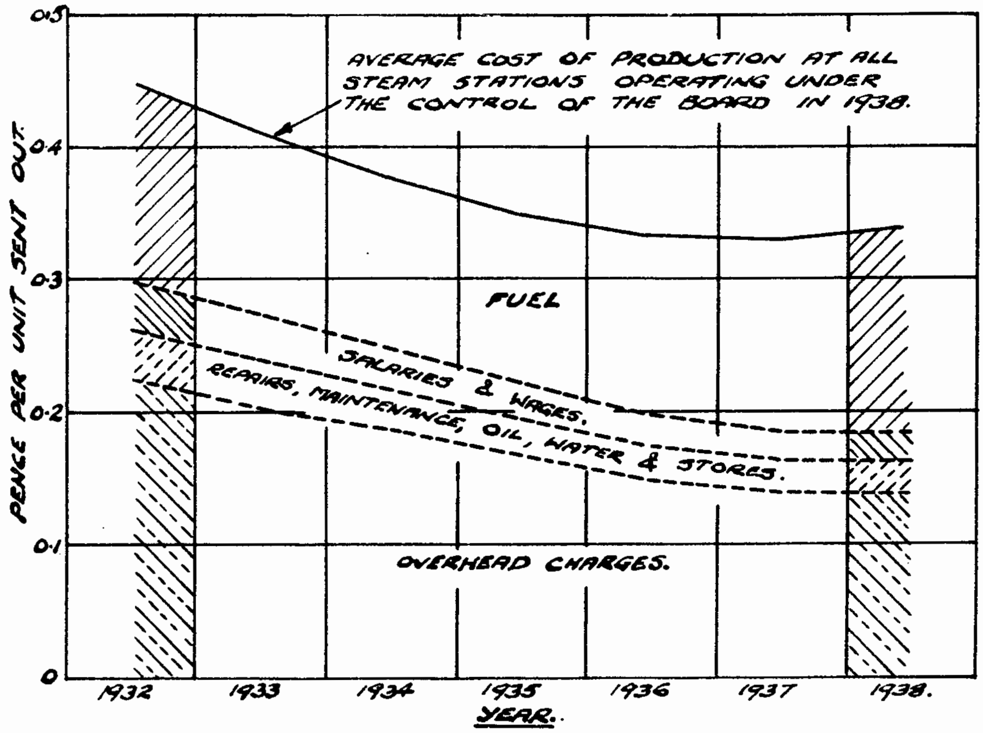


FIG. 4

CENTRAL ELECTRICITY BOARD DATA SHOWING COST OF PRODUCTION AT ALL STEAM STATIONS OPERATING UNDER THE CONTROL OF THE BOARD 1932 TO 1938

FROM.........(3).

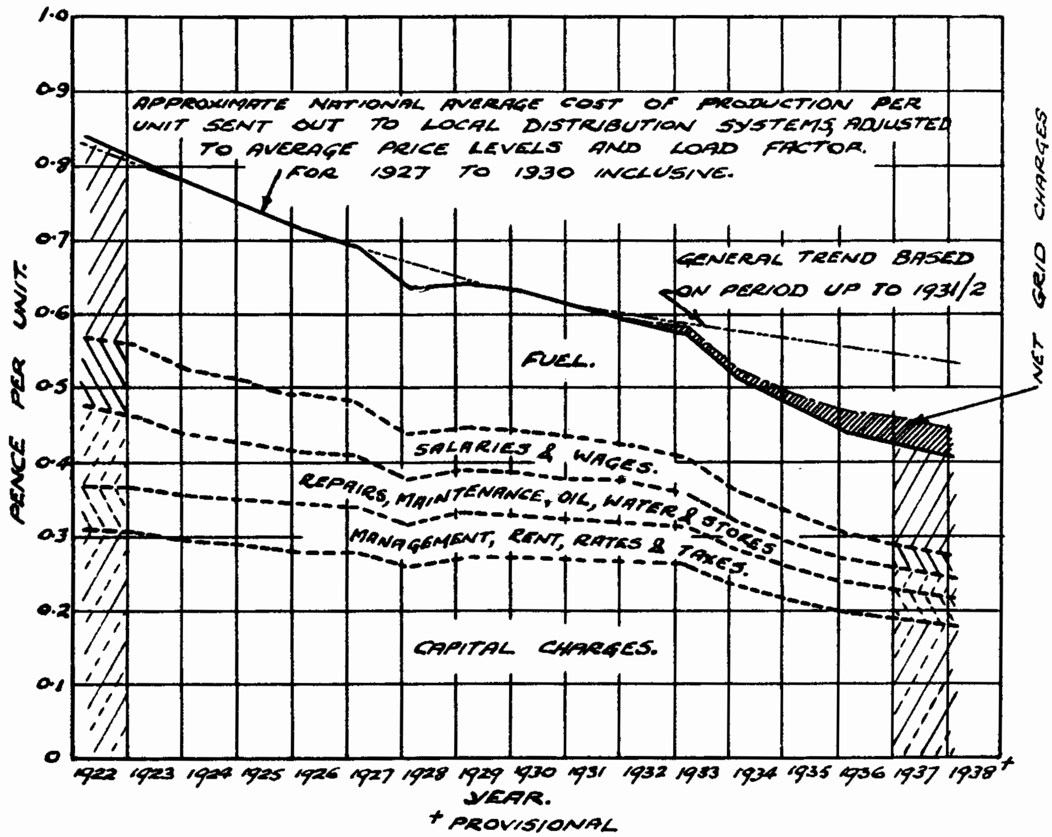


FIG. 5

CENTRAL ELECTRICITY BOARD DATA SHOWING APPROXIMATE NATIONAL AVERAGE COST OF PRODUCTION PER UNIT SENT OUT TO LOCAL DISTRIBUTION SYSTEMS (1922 TO 1938)

FROM......(3)

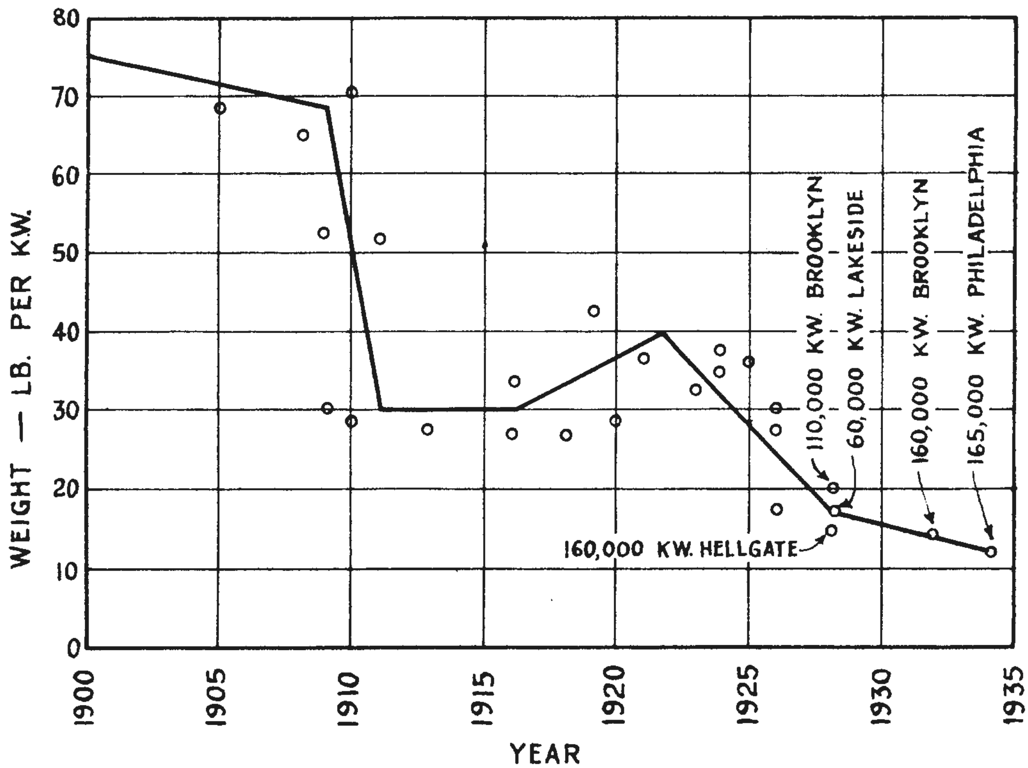


FIG. 6

WEIGHTS OF CENTRAL STATION TURBINE UNITS.
MAIN TURBINE AND GENERATOR EQUIPMENT ONLY

FROM......(2)

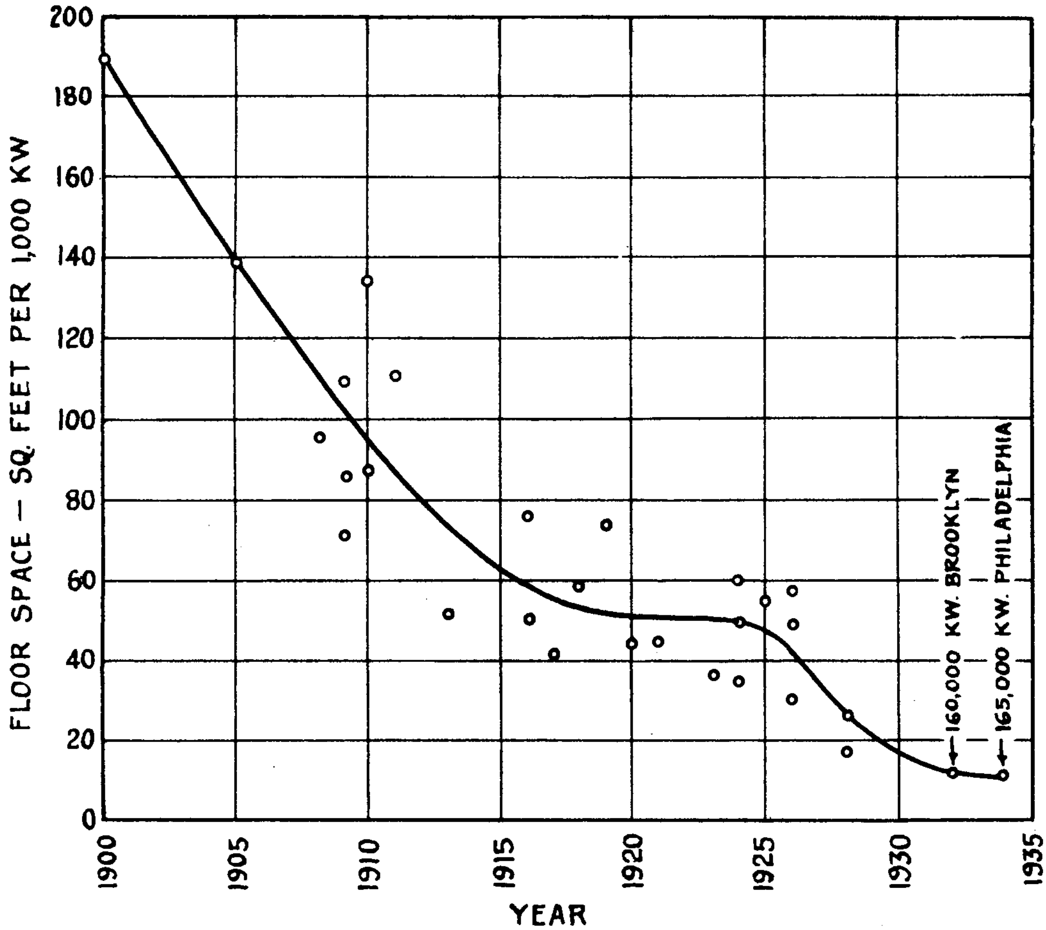
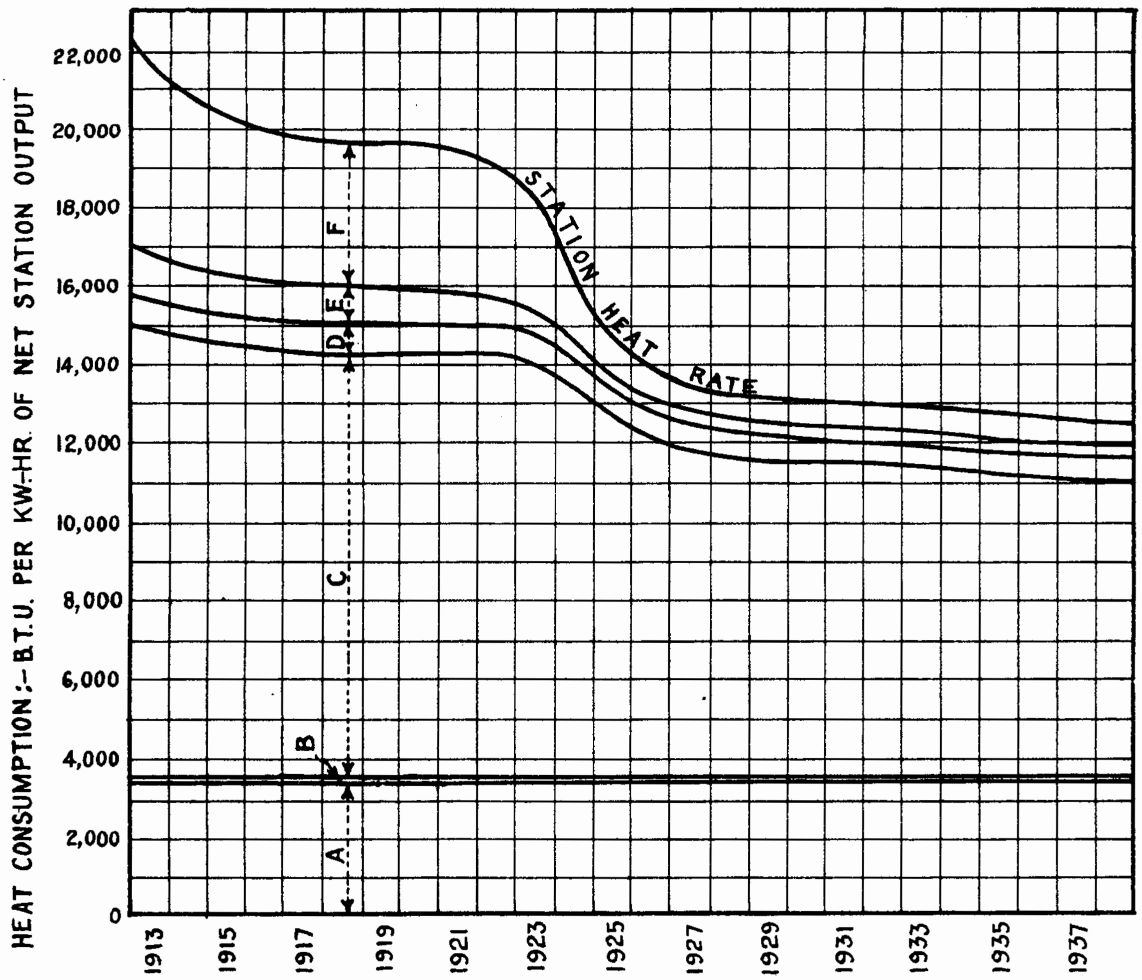


FIG. 7

PROGRESS IN FLOOR SPACE REQUIREMENTS OF CENTRAL STATION TURBINE UNITS INCLUDING TURBINES, GENERATORS AND GOVERNING EQUIPMENT BUT NOT HOUSE GENERATORS OR EXCITERS

FROM......(2)



KEY

A I KW.-HR. DELIVERED TO OUTGOING LINES
B UNRECLAIMED GENERATOR AND BEARING FRICTION LOSSES
C HEAT REJECTED TO CONDENSER CIRCULATING WATER
D AUXILIARY POWER
E STRAY LOSSES
F HEAT IN FLUE GASES AND UNBURNT FUEL

FIG. 8

AVERAGE PERFORMANCE OF 50 TYPICAL (AMERICAN) STATIONS, 60,000 KW. CAPACITY AND HIGHER, PLOTTED AGAINST DATES OF INITIAL OPERATION

FROM.......(2)

(*a*) Due to the very rapid progress of our electrical and mechanical colleagues, and the continuous expansion of the industry, the civil engineer has been engaged mainly in evolving new foundations, structures, circuits, etc., to suit the ever changing conditions, with the result that there exists very little basis for comparison.

(*b*) When the electrical and mechanical engineers increase investment costs, they almost invariably expect the refinement to justify itself by way of reduction of operating costs. Much of the work—in fact most of the work—of the civil engineer is not directly allocable to an operating circuit, the efficiency of which can be measured in ordinary terms. With few exceptions, the main portion of his efforts is reflected in the fixed charges sections of the total cost curve. Moreover, much of his work is reflected in the " No Load " costs, i.e., costs necessary for any production to be possible at all, and independent of character and amount of operation.

(*c*) Civil engineers bear the brunt of what, for lack of a better word, may be termed " Corrective Capital Investment". Thus, in the matter of installing 30,000 kW, the design and erection of such a set is obviously the same for Brighton as for Bristol. But the supporting of this machine gives rise to problems for the civil engineer which may differ widely for the two sites. One site may have excellent foundation subsoil. On the other there may be no rock or ballast suitable for foundations nearer the surface than, say, 100 ft. The civil engineer, therefore, has to correct the standard price per kilowatt installed by an amount depending on the nature of the site. For this reason all capital figures quoted in the form " Cost per Kilowatt Installed " must be studied in close relation to the site problems concerned, otherwise the expression becomes meaningless from the point of view of making real comparisons. This is particularly true of work carried out abroad, where in addition to site problems, the added costs of shipping, railage or haulage, and probably customs duties, have to be considered, and estimates of cost, based on cost per kilowatt installed, must make suitable allowances for these varying factors.

Despite these difficulties it becomes not merely interesting but necessary to look into the question as it affects us and to decide for ourselves whether saturation point has been reached in the matter of economic design and construction, and the directions in which improvements are possible.

For maximum benefit such an investigation would have to be carried out in great detail, and would comprise a major work well beyond the scope of this thesis, which has as its object more the indications of lines of thought than the enunciation of theorems specific, and which could perhaps serve as spade work for such a fuller investigation.

The problems facing the civil engineer cannot be orientated properly without a background knowledge of the main underlying principles common to such schemes, and of the main directions from which modifications of theoretically ideal conceptions are to be expected. Some space is therefore devoted in the next chapter to a brief examination of these principles and influencing factors.

CHAPTER II

(A) UNDERLYING PRINCIPLES OR THEOREMS

(1) The Straight Line Energy Theorem

In his book, " Large Electric Power Stations," Dr. G. Klingenberg wrote thus :— " . . . A survey of the process of power production from coal shows how the transport and conversion of energy moves along a straight line ; all auxiliary processes branch off from this line at right angles. The idea underlying all suggestions for improvement in that straight line of conversion, as well as the branches of auxiliary processes, should be shortened as much as possible."

This statement may be taken as fundamental theorem number one. That it holds to this day may be verified by studying the outlay of any modern super station. The theory is represented diagrammatically in Fig. 9 (4). The main energy circuit is represented by the coal travelling in a straight line to the boilers where it is converted into steam, which travels in a straight line towards the turbines in the engine room, to give mechanical energy which is converted into electrical energy by the generators whence it passes out to the substation and consumers. Under the auxiliary processes are included the cooling water for the condensers, the feedwater for the boilers, the air circuit through the boilers and chimneys, and the air circuit for cooling the generators.

Fig. 10 shows the site plan for Barking Power Station (6), which is a good practical illustration of the application of this theorem. Like all theorems, the ideal conception cannot, of course, be achieved in practice. Certain factors of influence, to be described in the second half of this chapter, force the engineer to deviate from this ideal arrangement. But the deviations where necessary come themselves within the scope of the theorem, in so much that they should in turn bend away from the " shortest possible " route as little as possible.

The recent tendency to the " unit plan " in the U.S.A., i.e. one boiler per turbine, is merely a further expression of this theorem, in that it suggests the shortening of the energy line by reducing the number of distributing points of coal in the boiler house, and the steam mains, etc., to the turbines.

Mr. George A. Mills, former president of the Kansas Electric Power Company, describes in the *Electrical World*, January, 1940 (7) a very interesting example of the unit plan under the heading " Low Cost Single Unit Plant for Kansas Utility." Although the installed capacity is only 10,000 kW and therefore does not, strictly, come under the heading of " Large Stations," the ideas of the unit plan are clearly defined. This power plant combines construction and operation economy with several novel design features. The main plant

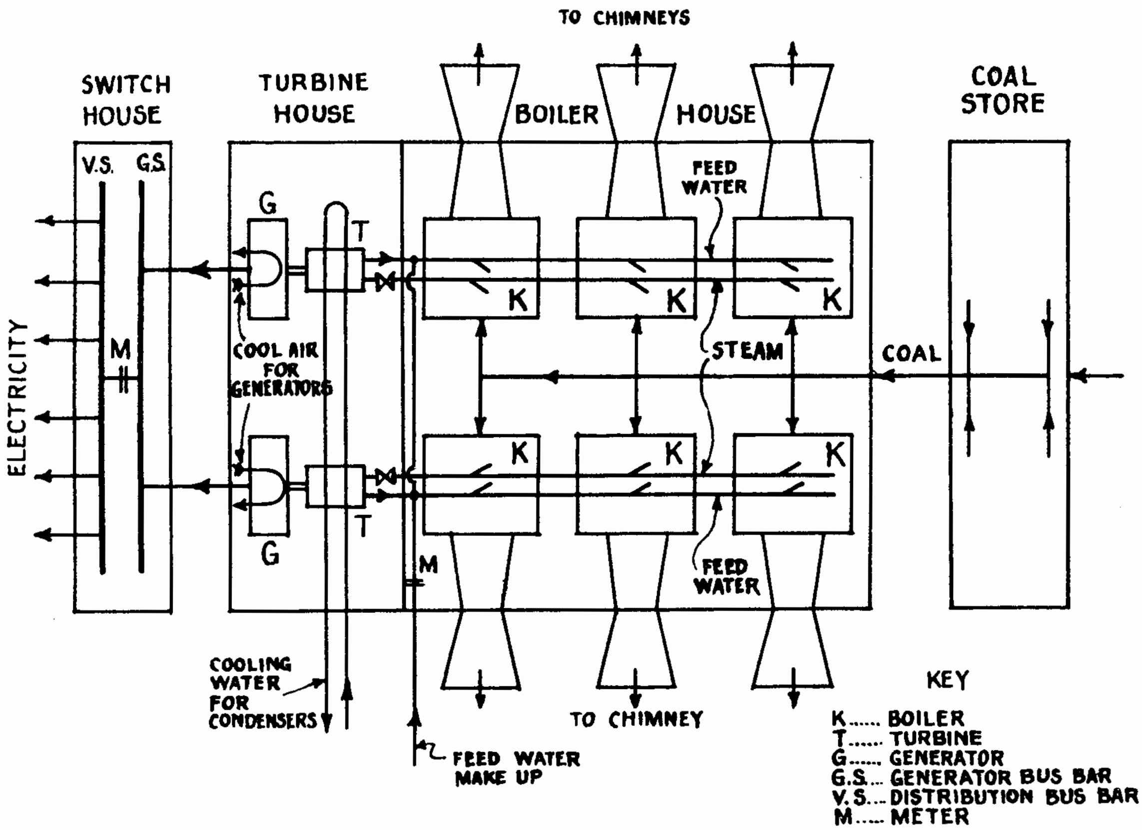


FIG. 9

ENERGY DIAGRAM FOR POWER STATIONS

FROM.......(4)

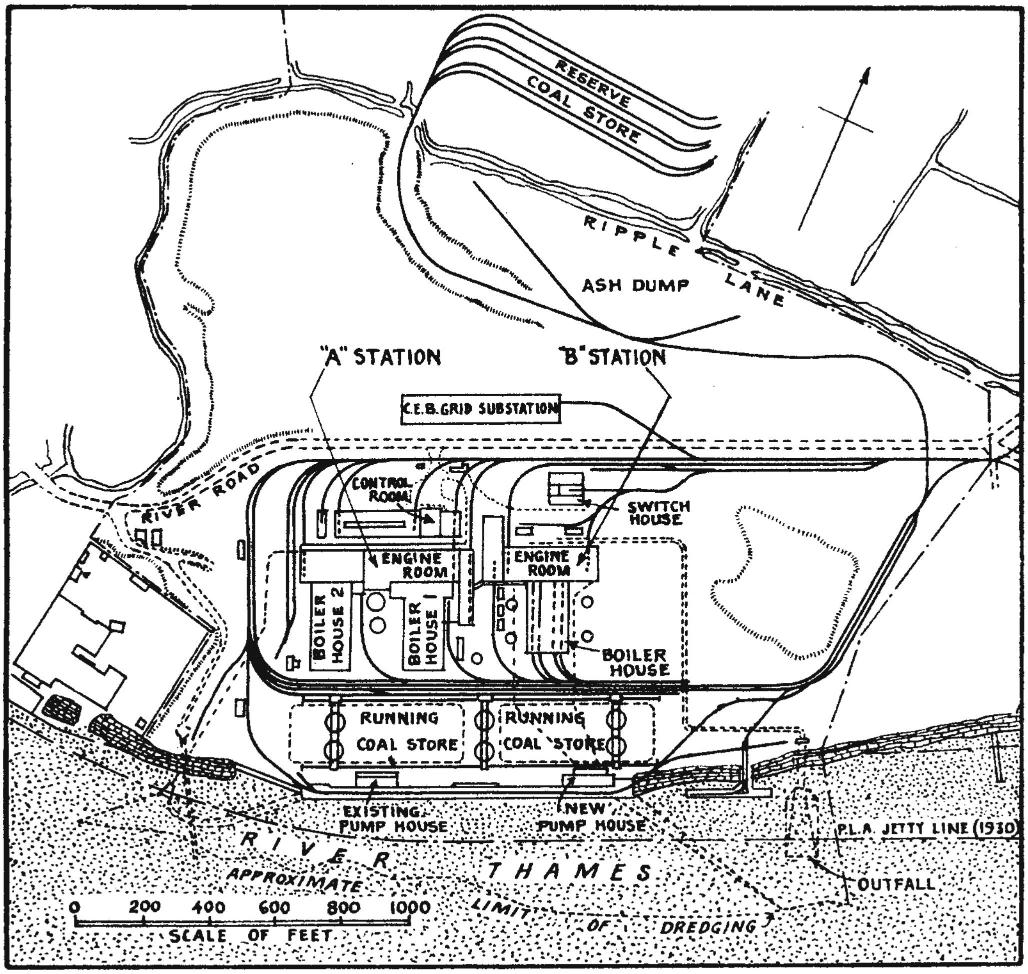


FIG. 10

SITE PLAN OF BARKING POWER STATION

FROM..........(6)

building is windowless, and controlled ventilation and modern lighting ensure the comfort of the operators. By eliminating the usual curtain wall the turbine and boiler rooms are thrown together, utilising a minimum of space. This arrangement, coupled with the fact that most auxiliaries are on the main floor, simplifies operation and centralises control.

(2) Economic Motive and Master Economy

The marketing of cheap but reliable power at a profit may be said to constitute the economic motive for undertakings of this nature. The engineer, situated between the promoter and the consumer, has to translate by virtue of his constructions, etc., first, money into energy, and then energy into money again, in order to close the cycle. But in the course of this money-energy-money cycle he has to gain sufficiently on the original money stream to content the promoter(s) of the scheme. This introduces pound-years into his calculations to a greater extent than for any other engineering undertaking. It follows that, in order to be able to weigh all the factors and give of his best he must be familiar with the business of the promotor(s), to a certain extent, at least.

One such money-use cycle is shown in diagrammatic form in Fig. 11. The relative amounts of money subscribed by bond and shareholders do not concern the engineer as a rule. What does concern him is the rates of interest and depreciation—i.e. the cost of money-use.

One of the first problems to arise is the question, " How much money to invest for a given undertaking ? " From Fig. 11 it is seen that, after earning annually the production costs, e.g. fuel, salaries, maintenance, transmission, supplies, taxes and insurance, the project has to earn interest for the bond-holder, dividend for the shareholder, amortisation fees for redemption of bonds after a given time, and depreciation, which ensures that, when the capital loan has been paid off, sufficient reserve will have accumulated either to rebuild the station or to make possible the necessary extensions for continued profitable operation. The methods by which amortisation and depreciation funds are operated comprise a study on its own. In recent years the " sinking fund " method would seem to have become the most popular (2). The method is to set aside each year, such a sum which, invested at a certain interest rate, compounded annually or half yearly, will amount to a sum equal to the amount of the depreciable property at the end of its life.

Fig. 12 shows graphically how, by this method, the annual increments paid into the depreciation fund are smaller than those which would be required by the " straight line method," say. The example is for an invested capital of £12,000 with a scrap value of £2,000 at the end of 10 years, the interest rate being 5 per cent per annum, compounded annually.

If S is the sinking fund or amount to be provided by equal deposits at the end of each year, and D is the annual deposit, n the number of years of operation of the fund, r the rate of interest, then :—

$$D = \frac{S\ r}{(1 \text{ plus } r)^n - 1} \qquad (21)$$

The process is somewhat similar for amortisation funds.

The charges for profit, amortisation and depreciation are classified as " fixed " in the sense that they are not dependent on extent of operation and are fixedly proportional to investment. The production cost charges are classified as partially fixed and partially variable. Thus a certain amount of transmission cost is chargeable to capital and only the costs which vary with the extent of the operation are admissible to " variable " or " operating " charges. Insurance and taxes come under fixed charges, and fuel, maintenance and salaries are split between fixed and operating accounts. By this method it becomes possible to express the lump sums of capital invested into annual values (capitalised cost) which, together with the annually recurring operating costs give the total annual costs for the project. Most of the evidence shows that the station cost characteristic is practically a straight line. With this characteristic, an anticipated annual load curve from total connections may be translated into an annual cost curve, which also shows at a glance the relation between fixed and operating costs. Figs. 13 and 14 provide examples of the method.

Thus the matter of how much money to invest resolves itself into a problem of selection and grouping of plant, etc., and the proportioning of operating and fixed charges so that the final amount selected for investment will, with a given income, ensure appropriate contentment for the promoter(s).

The final selection is best done with the aid of a curve or series of curves as shown in Fig. 15. The fixed charges line OZX is purely proportional to investment and the slope represents the sum of the weighted cost of money, taxes, insurance and depreciation, etc. Ten per cent has been assumed in this case. Justin and Mervin (10) use throughout the value 13½ per cent, made up as follows :—

	Per cent
Weighted cost of money	7
Taxes and Insurance	2
Depreciation	4½
Total	13½

The operating charges curve, DY, can only be drawn by preparing alternative schemes. The total costs curve, the sum of OX and DY, is then represented by DCHBAF. EJFX represents an annual income from power sales of, say, £30,000, which, in conjunction with the total costs curve becomes the datum for profit and loss.

A glance at the curves shows that for investment up to point D no operation is possible. From D-J operation is possible at prohibitive cost and loss ; after J additional investment ensures operation at profit. If EGH represents the promoter's contentment line, say 5 per cent, then the target to aim at lies between investment G and H, for in that zone the promised profits exceed the contentment curve, i.e. what the promoters could get by investing elsewhere. After G, every additional pound invested increases not only the profit earned but also the profit per pound invested, as is shown by the increasing slope of the line through E tangential to the total cost curve, until investment L is reached, where this slope is a maximum. At investment C the profit earned is a maximum, but every additional pound invested earns a profit per pound, not only less than the maximum possible, but less than the owners' contentment of 5 per cent, as it would at M, where the slope of the curve is the same as that of the contentment line.

It is obvious, then, that ideal investment is at M, and Master Economy may be defined tentatively as the design and co-ordination of works to result, on completion, in the achievement of a figure for investment, which ensures profit above the contentment line, and that the last increment invested still earns a profit equal to or greater than the promoters' contentment.

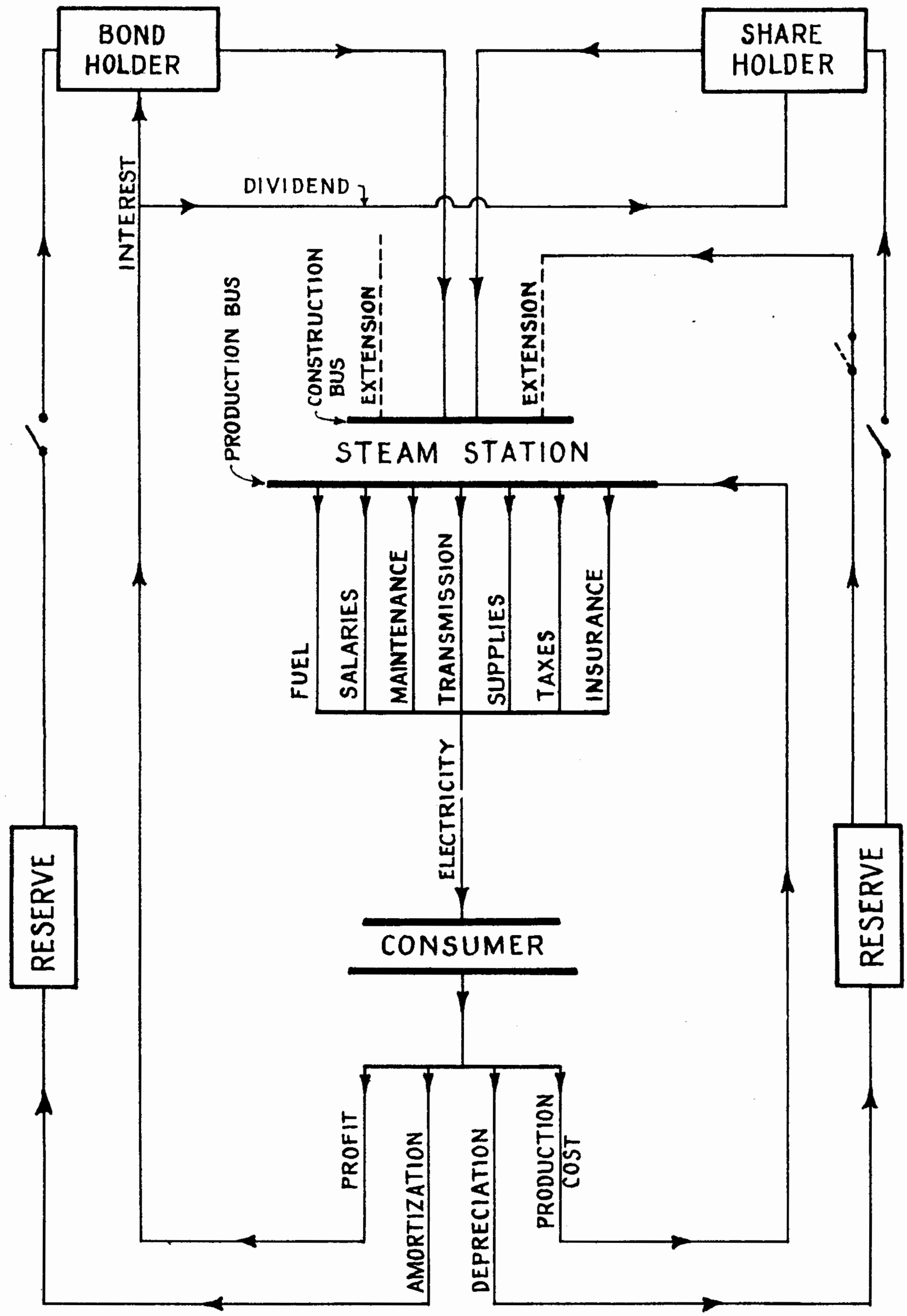


FIG. II

MONEY USE CYCLE— DIAGRAMMATIC REPRESENTATION

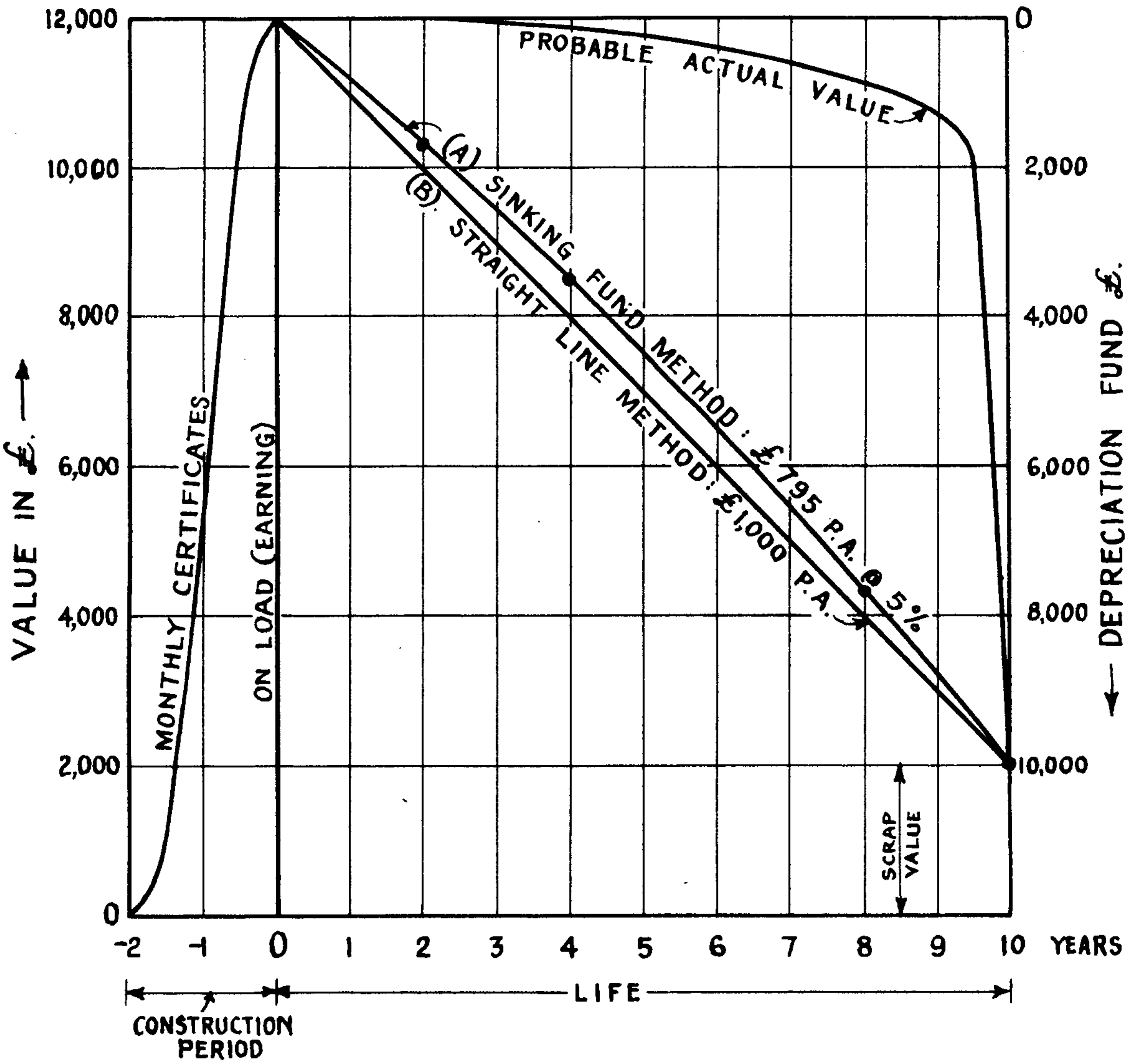


FIG. 12

ILLUSTRATING METHODS OF PROVIDING FOR DEPRECIATION

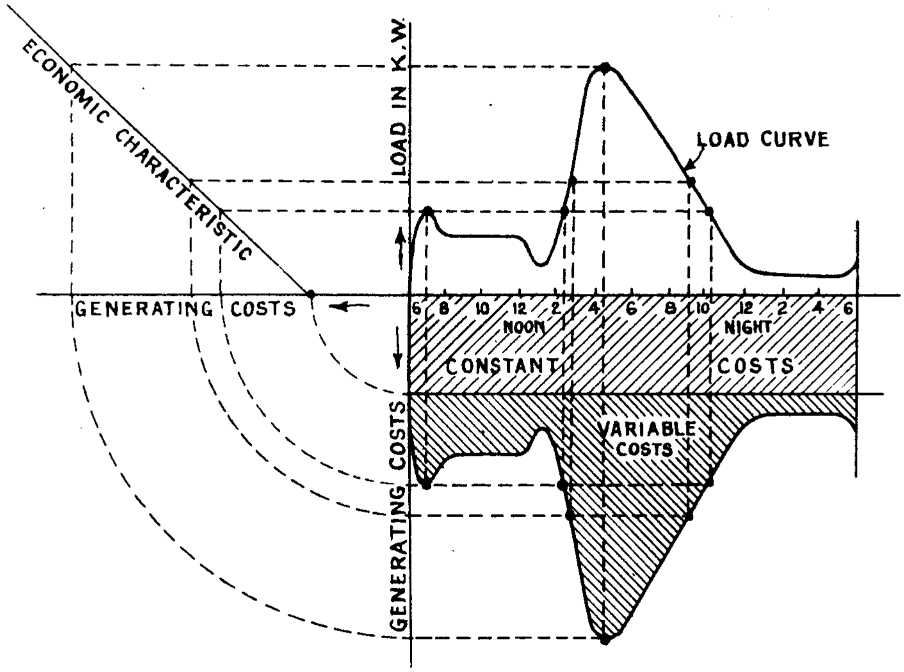


FIG. 13

TYPICAL ECONOMIC CHARACTERISTICS AND DAILY WORKING COSTS DIAGRAMS FOR A STEAM GENERATING STATION

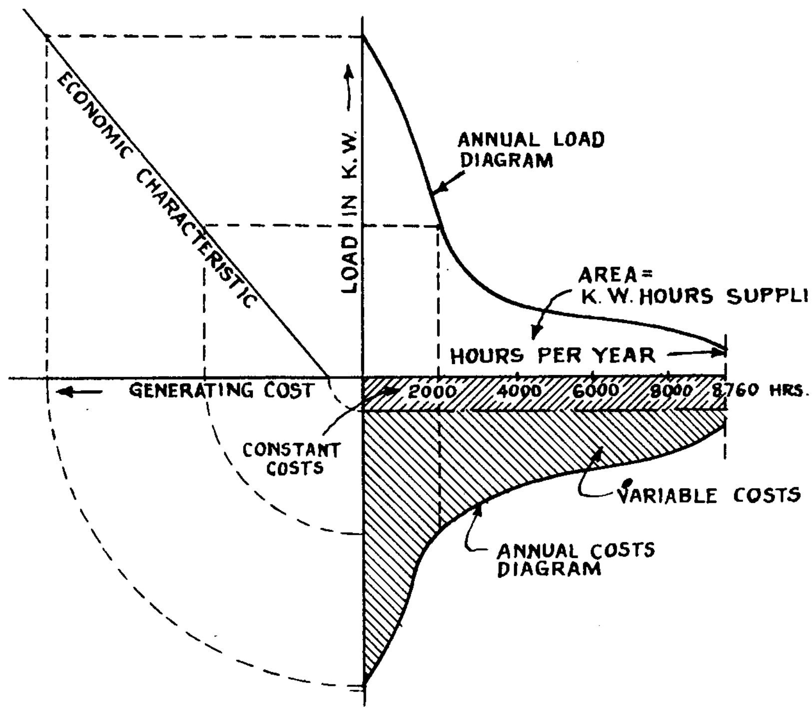


FIG. 14

TYPICAL ECONOMIC CHARACTERISTICS AND ANNUAL COSTS DIAGRAMS FOR A STEAM GENERATING STATION

This " last increment " of investment becomes very important in power engineering, where so many contractors and different manufacturers have to be handled. Moreover, the last pound has often to be spent for special purposes, e.g. national security, public interest, etc. The selection of design investment, therefore, requires great ingenuity as regards plant, efficiencies, materials, factors of influence, etc., and the " steering " process required in order to achieve this selected figure requires the highest skill in co-ordination.

This type of curve given in general here recurs in varying forms throughout power engineering, and it may be of interest to enumerate a few of the factors responsible for a tendency to cloud the issue when it comes to the exact location of ideal investment for master economy.

(*a*) *The Assumption Element*

This element is present in all forms of engineering and is unavoidable until knowledge of materials becomes perfect ! For this reason " sound " engineering judgment can only be based on experience—wide and various. Pile lengths and foundations, for instance, are based on trial pits or boreholes which, for obvious reasons, are kept at a minimum. The assumption is that the layers of strata are not discontinuous between such boreholes, and real engineering lies in the siting of such pits and holes to provide the maximum guarantee for the above assumption. Since stock sizes of piles cannot be kept on the shelf as it were, a few sizes have to be selected for casting. Now a cut-off of 10 ft in a 50-ft pile represents a loss of 20 per cent, and this loss is possible if variations in the strata render the selected sizes unsuitable.

Again, in the estimation of plant performance careful distinction must be made between contractors' or manufacturers' " claims " and their " guarantees " for efficiency.

The civil engineer is also affected by this element by virtue of the uncertainty of the materials at his disposal—especially in foundation problems. This subject has received much attention recently under the heading Soil Mechanics. This is a step in the right direction, though many of the assertions are not as yet beyond the controversial stage.

(*b*) *The Contingency Element*

Whilst the skill of the engineer stands him in good stead in the way of balancing out the errors accruing from the assumption element, he is more powerless against those wholly unforeseen errors accumulating under this item. Thus a sudden rise in the price of labour and material or a " blow " in the face of a pressure tunnel may result in a claim being lodged by the contractors at the end of the contract. The tact and skill of the engineer is often tried more in the unbiassed and just dealing with these claims than in attempts to prevent them.

The only antidote lies in allowing in the estimates a correct percentage as insurance against contingencies. This naturally " weights " the scheme to a certain extent.

(*c*) *Design Obsolescence*

During the course of the discussion on their paper, " Mechanical and Electrical Considerations : Fulham Base-load Station " (9), Messrs. Parker and Clarke declared that : " . . . Their own experience had shown them that no matter how carefully a complete power station was planned, and providing that the engineers were honest in reviewing pre-conceived plans as the work progressed, there were bound to be points which could only be decided as the works proceeded."

This puts the matter in a nutshell. A simple example would suffice. Holes in walls, ducts, etc., would be arranged for in the contract to the specification of the electrical engineers. But, during the tenure of the contract second thoughts, new researches, or other reasons may demand a re-arrangement of cables and ducts. Daywork items then creep in to cover for the filling in of old holes, the cutting of new ones in floors and walls, and re-arrangement of ducts.

Summing up, then, it would seem evident that, after the selection of the ideal investment point, much skilful co-ordination and judgment is required on the site in order to affect master economy. One conclusion becomes self-evident : the " outside men " must be carefully selected if the months of planning are not to be wasted in the long run. This applies to contractors as well as to consulting engineers.

(3) The Time Element

The time element pervades the whole of power engineering. The very definition of power implies time : one horsepower is the work done in transporting one pound through 33,000 ft per minute ! Energy is power $\times$ time. How the cost of power is affected by the plant factor is easily illustrated by the following :—

If each installed kilowatt were used throughout the year the fixed charges to be borne per kilowatt-hour would be 1/8760th of the fixed charges of installation per kilowatt. If, however, each kilowatt is only used for half a year the corresponding charges would be 1/4380th of the installation—charges, i.e. twice the above. This helps one to appreciate the constant cry for increased load and plant factors. J. S. Trelease, in his Presidential Address to the South African Institute of Electrical Engineers (22) quotes the case where 33 megawatts, the capacity of a " Klip " generator, is saved by the raising of the load factor from 73 per cent to 76·5 per cent.

Most engineers are familiar with the problems attendant on physical deterioration or depreciation of plant and materials. In order, however, to be more conversant with the time element in construction, as it affects civil engineers, it is necessary to appreciate also the prevalence and role of functional depreciation, i.e. obsolescence.

Table 3 shows the probable useful life expectancy of the principal parts of a steam station (10).

From this an idea may be obtained of the risks of physical depreciation. Obsolescence—which may occur suddenly or creep on slowly—is a more insidious disease. A plant designed for a useful life of 40 years may be obsolete in 10 years, that is, may have become inadequate to supply demands which have grown faster than anticipated. Rapid progress, new research, inventions, etc., all play a part in " outmoding " a machine. A glance at Fig. 1 shows how short was the life of each type of machine, from the small belt-driven unit to the large horizontal machine. And the advances in size for this latter type of machine is well illustrated by the following practical examples.

The Barking " A " Station, opened in 1925, housed four 40,000 kW and four 20,000 kW sets (6). The 1933 extensions required 75,000 kW sets—the then largest units in British service. Since then Battersea has installed a 105,000 kW set. The progress for America has been listed previously.

In order to cope with this situation American engineers have evolved the idea of superposition, whereby efficient, high pressure and high temperature sets are superposed on older and less efficient machines. Philip Sporn (11) reported in 1937 that " Where properly applied it was possible to install plant which were self liquidating from the savings over the old units and to gain the increments of capacity as a clear gain practically." He also mentioned four specific criticisms of the method.

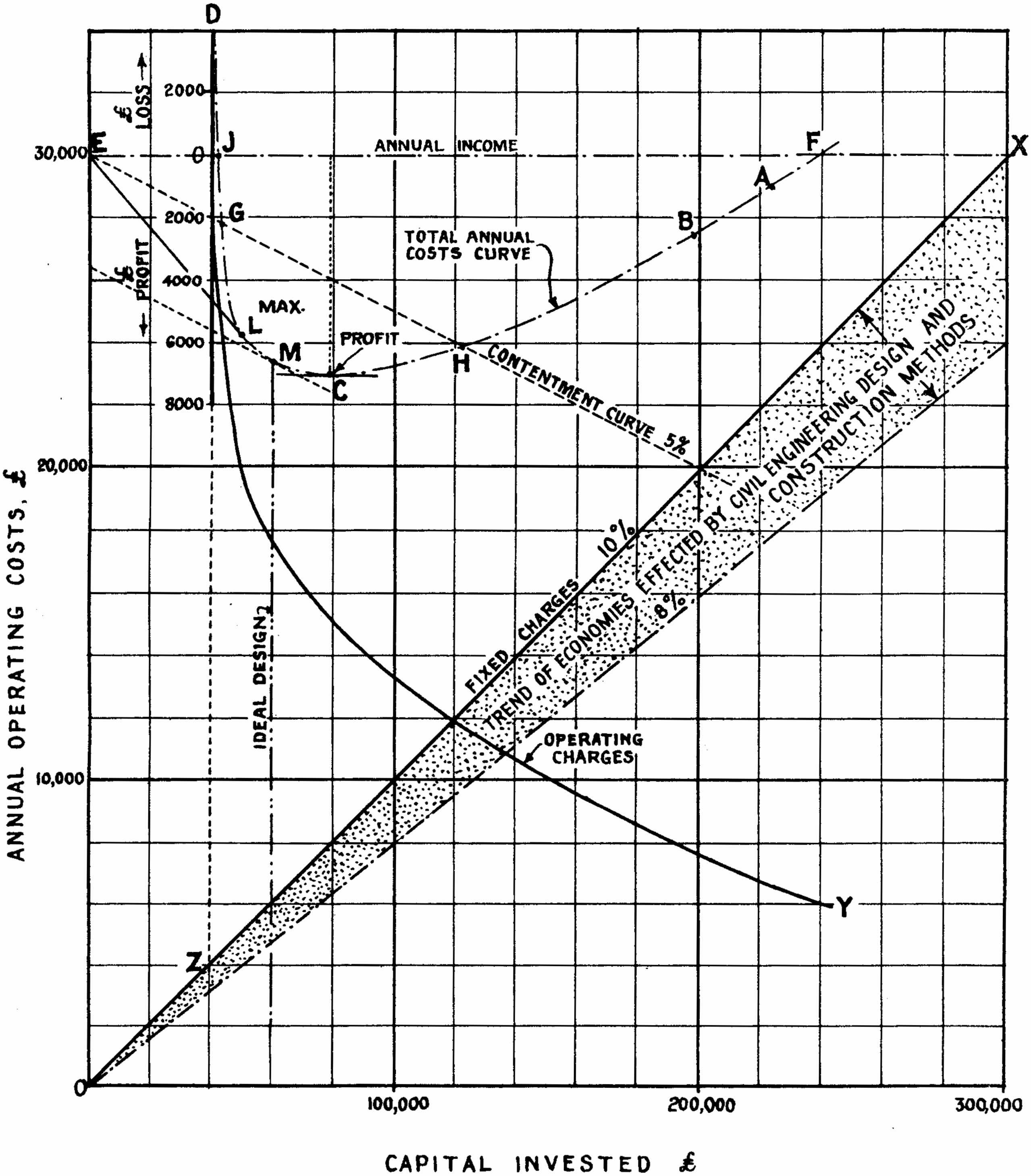


FIG. 15
IDEAL INVESTMENT AND MASTER ECONOMY CURVES

TABLE 3

USEFUL LIFE EXPECTANCY OF THE PRINCIPAL PARTS OF A STEAM POWER PLANT (10)

Description	*Probable Life Years*
Accumulators	15
Boilers, water tube	20
Boiler accessories	20
Breechings, steel	10 to 30
Buildings, brick	30
Buildings, wood or wood frame	20
Cables and feeders	15 to 25
Coal and ash machinery	20
Compressors, air	20
Condensers	20
Cranes	30
Economisers and air preheaters	15
Electric generators	20
Electric motors	20
Small steam engines	15
Steam turbines	20
Fences	12
Foundations	As equipment supported
Fuel oil handling equipment	20
Furniture and fixtures	15
F.W. heaters	20
Pipe and pipe covering	15 to 25
Pumps, reciprocating	15 to 20
Pumps, centrifugal	20
Stacks, brick or concrete	30
Steel chimneys	12 to 15
Stokers and other fuel-burning equipment	20
Superheaters	20
Switchboard and equipment	20
Tools and shop machinery	15
Transformers	15

For the Grid system where stations are loaded according to the " base load " method, or the " best point " loading method, or the " best incremental " method (as the case may be), stations and equipment will be graded according to efficiency, and the " grade number " does in fact reflect the position of the plant on the obsolescent front.

One method of coping with the situation generally would be to insert insurance in the money cycle, such as by increasing the depreciation fund.

The civil engineer, although his structures are rated safe against physical depreciation for periods from 15 to 75 years, must nevertheless make a contribution towards the avoidance of functional depreciation. This is best achieved by :—

(i) Shortening the construction period, thereby advancing the plant earning date as much as possible, thus ensuring profits from the early fruitful years which may come in handy later on when obsolescence threatens. The reduction in time factor actually means a capital saving as well, reckoned in terms of interest on construction, and capital to be amortised.

(ii) Designing liberally as regard space and foundation strengths, so that alternative plans may be put into operation, having regards both to demand trends and economic limits.

TABLE 4

UNIT INVESTMENT COSTS FOR A BASELOAD STEAM STATION AS TAKEN FROM A. E. KNOWLTON, FOURTH STEAM STATION COST SURVEY (AMERICAN) "ELECTRICAL WORLD," DECEMBER 2nd, 1939 (12)

Rating, M kW	75 to 100
No. of units condensing	1
No. of boilers	1
Steam pressure, lb	1,390
Steam temperature, degrees F.	835
Fuel used	Coal, pulverised

Investment	*$ per kW*	*Per cent of Total*
Land	5·24	4·96
Buildings and foundations	21·29	20·12
Condenser supply works	1·83	1·73
Fuel handling, storage	19·03	17·96
Ash handling	0·75	0·71
Boiler plant	13·24	12·52
Draft system	1·48	1·40
Feedwater system	3·01	2·84
Piping system	3·02	2·85
Turbine foundations	0·93	0·88
Heat recovery apparatus	1·79	1·70
Generator coolers	0·24	0·23
Turbo-generators	17·01	16·08
Turbine auxiliaries	3·22	3·04
Switchgear, wiring	8·05	7·61
Outdoor switching	5·69	5·37
Total Station and Switchyard Investment per kW	$105·82	100·00

(Approximately £26·4 per kW with 4·03 dollars assumed to the £.)

(B) FACTORS OF INFLUENCE

In practice, when the design and construction of a project is under consideration, many factors emerge which have to be taken into consideration, and which are instrumental in affecting the designs. Some of the chief factors are briefly examined below :—

1 (*a*) **Land (or site) Factor : Price of**

Table 4 shows the investment costs for a baseload steam station in America (12).

Table 5 shows similar costs for a British baseload station (9).

In the case of the former the cost of land amounted to 4·96 per cent, and in the latter to 8·64 per cent, or nearly double.

TABLE 5

COST PER KILOWATT INSTALLED—FULHAM BASELOAD STATION (9)

Section	Cost (£) per Kilowatt Installed	Percentage of Total Expenditure
Substructure	1·192	5·45
Superstructure	4·340	19·85
Circulating water system	0·631	2·89
Coal transport and attendant facilities	1·330	6·10
Land	1·885	8·64
Coaling plant	0·427	1·96
Steam generating plant and mechanical plant	7·080	32·30
Electrical equipment	1·934	8·86
Gas-washing plant	1·282	5·85
Cost of loans, interest, engineering fees	1·730	7·92
Miscellaneous items	0·039	0·18
Totals	£21·870	100·00

The above capital costs (Table 5) included for :—

(*a*) Air-raid precaution measures.
(*b*) Provision of four sea-going colliers.
(*c*) Gas-washing plant.
(*d*) Housing for transmission switchgear.

T. H. Carr (13) quotes the following figures for land cost :—

London area	£40,000 per acre
Provincial area	£50-£100 per acre

This price becomes very important when taking decisions on such matters as basement storage facilities, indoor or outdoor switching gear ; facilities for large coal reserves ; facilities for ash disposal ; the spacing out of buildings for air-raid precautions, etc.

The immediate reaction in the case of expensive land is to try and increase the design density—megawatts per acre. This makes for greater heights with heavier foundations, difficult pipe runs, pumping charges increased, and may cause trouble through interference with " Ancient Lights."

Assuming it was possible to produce the 540 mW on the 49 acres of the Klingenberg Station, Berlin (5), this would give a design density of 11 mW per acre. For Fulham Power Station (9) 25 mW per acre is achieved on the basis of 310 mW on a site of 12½ acres. For Battersea Power Station it was scheduled to attain 500 mW on a 15-acre site, giving 33⅓ mW per acre (15).

1 (*b*) Land (or site) Factor : Nature or Type

The nature of the subsoil necessarily determines the type and hence the cost of foundations. For a site where the subsoil consists of deep layers of peat, silt, muck, etc., piling may have to be resorted to. Where there is a chance of distributing the pressures imposed on the subsoil to a figure which could be accepted within reason, a raft foundation may be adopted. On good foundation soil the ordinary slab and beam foundations would be adopted.

Practical illustrations are :—

Fulham Power Station

Stiff river mud	+18·0 to 0·0 O.D.
Ballast	0·0 to −12·0 O.D.
London Clay	−12·0 to ? O.D.

O.D. = Ordnance Datum.

The raft foundation was adopted (14).

Battersea Power Station

" Vibro " piles carry some of the loads whilst bearing was taken directly on the clay in other instances (15).

Thus the chimney towers were founded directly on clay giving a pressure of 3·53 tons per sq. ft. A base slab 6 ft thick was used to distribute this pressure.

Barking Power Station A and B

Reinforced concrete piled foundations were adopted throughout, typical boring data being as shown in Fig. 16.

Again, the general level of the site with reference to river, sea, or water table level, plays an important part in influencing design. Where risks of flooding exist, expensive precautions may have to be taken to guard against this, or the depth of basements which could have been usefully employed for ash handling, electrical switchboards, storage, etc., may have to be limited, due to risks threatening continuity of service. Imported filling, to raise site level to above flood levels may constitute a major item in the costs schedule. Tide levels predetermine jetty levels, condenser settings, etc., and thus have a bearing on pile lengths, excavations, and so on.

The chemical qualities of the subsoil exert an influence on the specification for piles, foundations, and pipes, which is duly reflected in the costs of the job.

1 (*c*) Land (or Site) Factor : Location of

Questions such as load demand, coal and water supply, cost of electrical transmission of energy, cost of land and pertaining taxation demands control the location of sites.

It is noteworthy that in all the above cases where land factors influence the design, the influence is on the whole exerted on the civil works, and yet the civil engineer has no control over these factors, which are included in the hypothesis, as it were.

Firstly, there is the question of aesthetics. If sited in a progressive community, town or

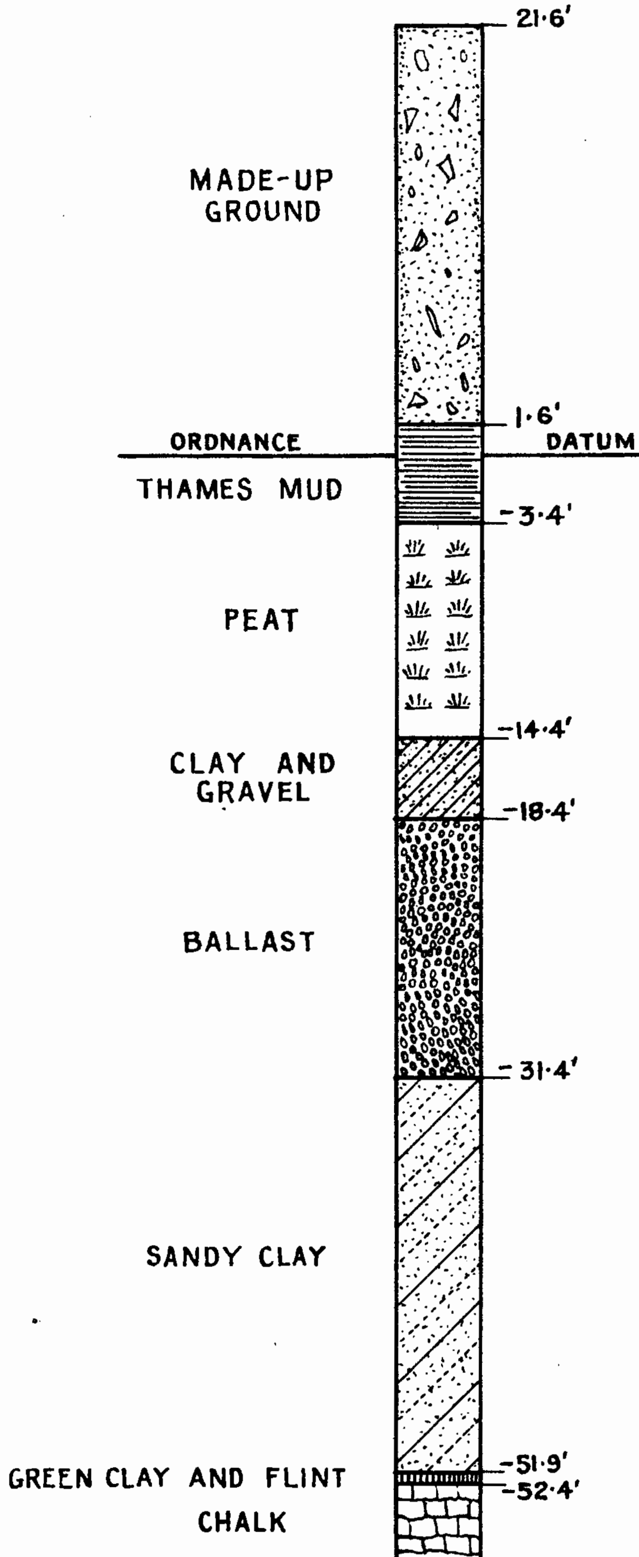


FIG. 16

TYPICAL BORING DATA
BARKING POWER STATION (C.L.E.S. Coy)
(BY COURTESY OF SIR ALEXANDER GIBB & PARTNERS).

TABLE 6

BATTERSEA POWER STATION
CAPITAL COST

Constructional work only, excluding interest, consultants' fees, etc. (15) :

	£	£
Site		
Land	556,600	
Demolition and levelling	12,710	
Boundary fence	5,200	
Roads and sidings	26,400	
Landscape gardening	1,500	
		602,410
Main Buildings		
Foundations		
Trial and boreholes	3,500	
Steel pile surround	48,400	
Unwatering site	10,470	
Foundations	164,000	
		226,370
Superstructure		
Boiler house	305,800	
Switch house	188,200	
Turbine house	120,300	
Chimneys	13,520	
Turbine foundations	18,700	
Drains	10,400	
Water mains (town)	1,770	
		658,690
Coal and Ash Conveying Plant		
Coal store	51,200	
Coal conveyors (housing foundations)	41,700	
Wagon tippler house	8,880	
Ash sumps	27,800	
		129,580
Gas washing and grit eliminating plant		229,150
Workshops and stores	13,600	
Gateshouse	1,500	
		15,100
Jetty, barge, berth, etc.		136,000
Circulating Water System		
River screening chamber	41,600	
River grid screens	6,700	
Sluice gates	850	
Circulating water chamber	44,400	
Discharges chamber and tunnels	35,700	
		129,250
Internal Cable Tunnels		
North tunnel	7,000	
South tunnel	8,000	
		15,000
		£2,141,550

city, the superstructures will have to conform with the standards required by the local authorities. Unsightly outdoor plant may have to be avoided, and the question of " Ancient Lights " may arise, as it did in the case of Fulham Power Station (9).

Secondly, the smoke nuisance introduces extra investment and operating charges. High chimneys are required to diffuse the gases and, in highly built-up areas, it may be necessary to install gas-washing and purifying plant.

For Battersea (15) the cost per cubic foot of chimney worked out at 25·75 pence as against 10·566 pence for superstructure. Cost of chimney towers and foundations came out at 35·99 pence per cubic foot. The gas-washing plant and grit eliminators worked out at £299,150, or about 10·7 per cent of total cost, excluding interest and engineers' fees. See Table 6.

For Fulham (9) the cost of the gas-washing plant amounted to 5·85 per cent of the total cost.

Table 7 gives some idea of deposits from industrial and other sources in various localities throughout the United Kingdom.

TABLE 7

ATMOSPHERIC DEPOSITS IN TONS PER SQUARE MILE PER MONTH, FOR THE YEAR ENDING MARCH 31st, 1932, FOR LOCALITIES IN OR NEAR HIGHLY INDUSTRIALIZED AREAS THROUGHOUT THE UNITED KINGDOM (1)

Locality	Total Solids		Insoluble Matter		SO_3		Cl.	Rainfall
	*(a)	(b)	(a)	(b)	(a)	(b)		mm
London :								
Horseferry Road	31	40	20	27	3·4	5·6	1·2	50
Kew	5	7	10	12	1·6	2·2	0·5	52
Watford	14	24	5	18	2·0	2·8	0·7	69
Birmingham Central	28	59	18	38	2·2	4·7	1·3	62
Bourneville	10	15	5	9	1·0	1·6	0·6	70
Leeds Central	30	37	18	22	3·3	4·5	2·0	70
Leeds, Headingley	10	16	4	7	1·4	2·5	0·9	69
Liverpool	43	60	24	32	5·8	10·2	2·5	73
Salford	20	30	11	18	3·8	6·5	3·2	72
Rochdale	23	31	15	24	2·1	4·3	1·7	91
Southport	8	13	4	8	0·8	1·5	1·0	84
Sheffield	28	40	19	32	2·7	4·1	1·7	70
Rotherham	31	39	22	38	2·8	3·2	1·8	65
Stoke-on-Trent	18	27	13	18	1·9	3·4	1·4	75
Edinburgh, Princes Street	20	28	14	22	1·7	2·5	0·3	62

(*(a) = average. (b) = highest month)

2. Type of Station

The introduction of the Grid system or interconnected systems, has to a certain extent evened out the sharp distinctions between peak- and base-load stations. When the system first took over, stations of greatly varying efficiency were included and the most economical course was to let the most efficient stations carry the base load. More recently, and especially in America, there has been a tendency to operate hydro-stations in conjunction with steam stations ; the former to take the peak loads off the system curve. The low operating cost, speed of coming on load, remote control, etc., are all factors making hydro-stations suitable for such employment.

In Great Britain, the first example of such a plant designed to deal primarily with the daily peak is to be found in the Galloway Water Power Companies development. Investigation showed that the scheme would be economically satisfactory if it were laid out to give a load factor of 20 per cent in a year of normal rainfall (17).

In America, a good example of such operation is found in the Conowingo Plant, utilising the flow of the Susquehanna river. (Philadelphia Electric Company.)

Major Whitman (18) writes in *American Civil Engineering*, March, 1938 :—

"... Paradoxically, power can sometimes be supplied more cheaply from a combined system than from a system consisting of steam plants alone, even if the cost of the hydro is considerably higher than the cost of that part of the power which is generated by the steam. This is possible because the hydro will supply that part of the power in the load curve which comes on the peaks and which it would be more costly to generate by steam."

How the "load range" allocable to a station affects design may be illustrated by the following :—

For the 1923 "A" station, in the case of Barking Power Station, three small (168 h.p.) and three large (443 h.p.) circulating water pumps were installed. The reason for this was to attain the maximum economy of operation by enabling an approximately correct amount of circulating water to be used for various loadings of station. A similar arrangement was not found necessary for the "B" station, which was to operate on baseload, and one size of pumps were installed. Such a decision naturally affects the layout of pump house and grouping of pumps.

In the selection of turbines for baseload conditions the sustained efficiency of the large set is superior to that of the smaller sets, and the choice of such sets has an effect on civil engineering, as regards foundations, in weight per kW to be supported (see Fig. 6) and on the layout of superstructure, from space requirements per kW (see Fig. 7).

As regards coal firing boilers, for peak stations the installation of pulverised fuel boilers would be favoured, owing to the savings on "banking" during off-peak hours, and the speed with which a machine could be brought on load. Special provision has, therefore, to be made for crushers and mills, and the layout of boiler house differs from that contemplated for the installation of stoker fired units.

3. Co-ordination Factor

The designs have generally to be co-ordinated to satisfy such authorities as may be interested in the project. Quoting from Mr. Rider's discussion on Fulham Station (Parker and Clarke) (9) :—

". . . the station had to be designed to the satisfaction of the Central Electricity Board, the Electricity Commissioners, the London County Council, the Ministry of Health, the Office of Works, as well as the Fulham Borough Council. . . ."

The engineer has no control over this type of influence even though actual designs and construction times may be affected.

But over "internal" co-ordination he does, or should, exert complete control. The splitting of contracts into sub-contracts, in order to guarantee maximum output, quantity and quality, compatible with site access and storage facilities available, is very much his affair. The timing of commencement and completion of various operations also comes under this heading.

It is as well to remember this factor when drawing up the designs, because the quality and speed of construction is vitally affected.

4. Insurance against Fire and Possible Enemy Action

Fire precautions make it necessary to vet all designs carefully from this point of view. The installation of high-pressure pumps, self-closing louvres, and equipment for prevention of fire spreading, such as carbon-dioxide automatic equipment, all require extra investment. Materials of construction have to be non-inflammable as far as possible, and cover to reinforcement must be adequate to prevent spalding. Special walls may be inserted to prevent spreading to adjoining bays. Filling material under plant should be non-inflammable, such as clean gravel in which no pieces of timber are present, and of a type to drain away oil rapidly.

Prior to 1939 much attention was also paid to air raid precautions. The spacing out of buildings to reduce risks of being hit, the use of carefully thought out camouflage, the building of blast walls, and of sectionalising walls which would confine damage to a particular spot, the selection and location of windows, the designing of walls, etc., from the point of view of possible shocks, all received careful attention, and such attention was duly reflected in the cost. In many cases benefit was reaped, no doubt.

T. H. Carr (23) states that, of the five war hazards—sabotage, bombs, fire, balloon barrage trailing cables and aeroplanes crashing into overhead lines—the last two have caused the most trouble.

Perhaps the largest single factor of insurance against air damage, was the Grid itself.

Full protection or immunity could only be provided by siting well underground.

Future considerations will, no doubt, weigh up carefully the worth of capital sunk in protections which may only be called into action twenty or fifty years from the spending date.

In America, one suggestion for the ensurance of continuity of service was the construction of floating units of up to 60,000 kW, which could be navigated up rivers, or along coasts, and be "plugged" in to prepared switching and transmission systems.

CHAPTER III

ROAD AND RAIL ACCESS

In British practice the main civil engineering contract is often split into two portions : Contract I comprising the work connected with road and rail access up to the site, and Contract II comprising the main contract of foundations, buildings, circuits, etc. The method has some obvious advantages :—

(i) It allows for the use of expert contractors on this type of work, e.g. road and railway construction, whilst leaving the main engineering job to the chief public works contractor, if the nature of the particular job should warrant such a course.

(ii) If the main contractor also tenders for this job he obviously hopes to get the main contract finally. His interest in the durability of the access roads is, therefore, very real indeed, and this provides real incentive to sound work being executed.

(iii) This arrangement (whereby the main contractor elect executes Contract I) provides a good opportunity to observe the qualities and methods of the particular contractor, and may be of use where small contractors who have grown wish to tender for the bigger, i.e. more ambitious contracts.

For the purpose of this analysis there is no reason why road and rail access should not be classed as one of the circuits of energy, where, according to theorem 1, all suggestions for improvement should envisage the shortening of the circuit. The word " short " must be interpreted in its wider sense, and must, for instance, give due attention to the time element. Thus, if any proposed outlay tends to lengthen the period of time that an operating cycle, or a construction operation takes, the effects will be reflected in the costs of operation and construction. Any contractor tendering for the main works will pay close attention to the type and length of access it is intended to provide, and due allowances will have been made in the rates submitted in his tender.

That section of access falling between the junction with main trunk railways and main roads and the site boundary is not affected by the type or size of station, and the only special considerations would be to cater for heavy traffic during construction (such as 80-ton transformers) and for all-weather access during the operation period, or life, of the station, and for speed of construction.

Wherever possible, consideration should be given to placing road access alongside rail access, for the obvious reasons of simplifying maintenance problems, reducing first cost in bridges, culverts, embankments and cuttings, drainage and wayleaves, etc., all of which would not require full duplication.

Experience during the war has shown that it is a difficult matter to disrupt access by road and rail for longer periods than would be necessary to exhaust station reserves and thus threaten continuity of service. And so the argument for separation of road and rail access, with attendant increases in investment costs, hardly applies.

The planning of the access circuit within the site boundaries, however, requires careful attention. This applies more to rail than to road access, unless a very expensive form of road surface is under consideration.

Permanent access must provide for in and outgoing rail wagons and trucks. As regards coal—assuming all the coal is brought in by rail—a 240mW station steaming at 1·2 lb per kWh and plant factor 60 per cent requires :

$$\frac{240,000 \times 0{\cdot}6 \times 8760 \times 1{\cdot}2}{2240} = 676,000 \text{ tons per annum or about } 2,000$$

tons per day, i.e. 200 10-ton wagons or 100 20-ton wagons daily. Adequate shunting facilities must, therefore, be provided to deal with this average traffic.

Broadly speaking, two methods are followed in internal access planning. In one case the rails are taken directly to the salient points, e.g. coal tippler pit, loading bays in turbine and boiler houses, jetty, etc., and sidings are provided well off to one side where full and empty wagons may be shunted whilst waiting.

The other method is to provide " circular access " which means that the permanent rails are so planned that they circle the site, due allowance having been made for possible extensions and with short offshoots to salient points, thus providing automatic " storage " sections on the long stretches of loops. By providing double lines and suitable switches, empty and full wagons can be handled separately and kept in continuous flow.

The former type is common where coal is mainly rail borne, and the latter where the coal is mainly sea (river) born. Naturally, compromises exist between these extremes.

The great advantage of the latter method lies in the fact that, in a well-planned system, very short spurs taken from the main permanent loops would reach any sphere of likely activity by the contractors, during the period of construction, and this ensures the maximum use of permanent lines during the construction period, tending, not only to speed up construction, but to reduce costs. The disadvantage lies in the fact that road crossings are unavoidable, and that wherever the lines cross culverts, trenches, etc., consideration must be given to strength for taking the superimposed loads. The two methods are shown diagrammatically in Fig. 17*a* and *b*.

The 500 mW station at Battersea was provided with sidings proper for storage purposes, with a capacity of 72 wagons (15), i.e. an example of Method 1.

In the case of the New Dunston Power Station (24) the rail access may be described as fully circular, but reinforced with sidings incorporated in the loop. During construction approximately 4 miles of sidings were under daily use, serving all parts of the site.

From Fig. 10, showing the outlay of access at Barking Power Station, it is seen that " circular " access has been adopted, full allowance having been made for extensions at a later date. Very short spurs, tapping the main lines anywhere, would reach possible sites of activity with the minimum cost and trouble. Storage sidings are incorporated in the loop

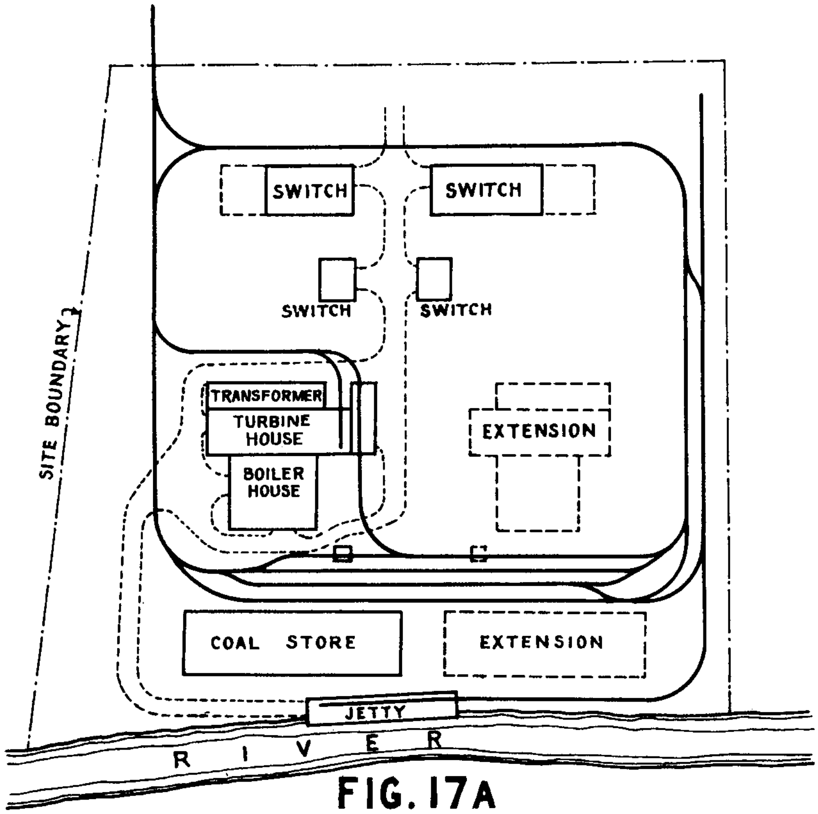


FIG. 17A

DIAGRAMMATIC ILLUSTRATION OF TYPICAL "CIRCULAR" RAIL ACCESS

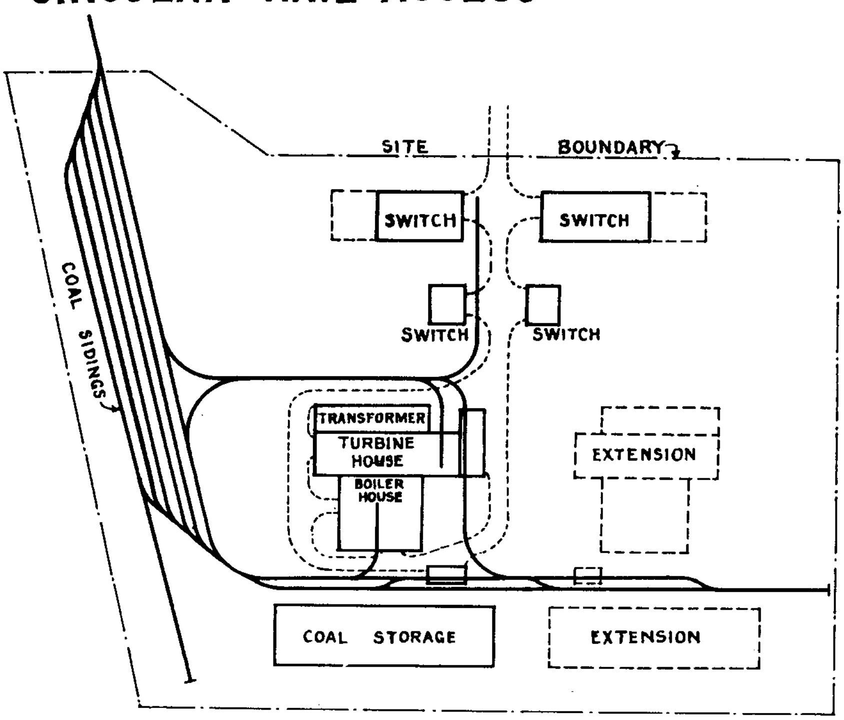


FIG. 17B

DIAGRAMMATIC ILLUSTRATION OF TYPICAL RAIL ACCESS (SIDINGS TYPE) FOR STATIONS WHERE COAL IS MAINLY RAILBORNE between the boiler house and running coal store. This may be cited as an example of Method 2.

Bollards and electrically operated capstans are usually provided near the sidings and filler pits to assist shunting operations.

In designing railway sidings for power stations, care must be taken to get the prior approval of the main line authorities concerned (and whose rolling stock will be involved) to all proposed clearances, switches, turnouts, curves, etc.

In Great Britain it frequently happens that stations have to be located on bad sites from the point of view of stability of subgrades. This is due to the fact that sites adjoining rivers or estuaries, so located for coal transport and cooling water purposes, are often marshy, and peaty and silty in character. Filling may then be required for raising the site to operation level, and the inevitable settlements produced form one of the greatest access problems, for it is an expensive business to keep raising rail tracks by injecting ballast under them, which is naturally more expensive than chalk, for instance. Cracking of roads is a factor operating against all-weather access. In such cases steps should be taken to place the embankments carrying permanent rail and road access as early as possible in the contract, and great care should be taken over the consolidation of such banks. Here an advantage of circular access is manifested. In this case the heavy traffic around the site during the construction period would assist in the consolidation of the permanent banks, whilst providing full access to the contractors. By the time that the station comes into commission and operators take over, the sting should have been taken out of the consolidation curve, which, as can be seen from Fig. 18, is very much a function of time. Obviously it is not necessary to lay all the lines at first for circular access. Only the main loops need be laid down at first circling the site. But the embankments should be made wide enough to take at least two lanes of motor traffic in addition to the full number of railway lines required. For, as Tersaghi has shown (25), width of embankment plays a most important part in stabilising sub grades. His stability formula gives a relationship as follows :—

$$p = \frac{wb\,(1 - \tan^4 A)}{2 \tan^5 A} + \frac{K}{\tan^4 A} + \frac{2\,c}{\tan A \,\mathrm{Sin}^2 A}$$

where p = ultimate bearing capacity of soil without further lateral displacement.

w = bulk density of subsoil.

b = half width of loaded area.

c = cohesive force per unit area of subsoil.

A = 45° — a/2 where " a " is the angle of friction of the subsoil.

K = The stress caused by the loading adjacent to the loaded area (surcharge) or by weight of displaced soil.

The principles of derivation of this formula are illustrated in Fig. 19.

The results of this formula cannot be used blindly. Thus the value of the formula lies more in the fact that it establishes the relative importance of factors than that it gives absolute values. The first term shows the function of internal friction ; the second term shows the value of counterloading ; the last term introduces cohesion.

It may be of interest to record here a practical example in which the working of the formula above was tried out. During the construction of Littlebrook " A " Power Station, first hand experience was had of this particular problem. The road and railway embankment had to be taken over a site having a soil-water-table profile as shown in Fig. 20, and typica strata as shown in Fig. 21.

The stages of the proceedings and results are set out in Fig. 22, which shows how stability was finally reached with counter-weights in the shape of extra fill placed on either side of the embankment proper, and which also did service as cable reserves.

Filling material "lost" in the marsh, due to settlements such as shown, could form grounds for a legitimate claim by the contractor.

It is interesting to apply numerical values to the formula for the case of the embankments shown in Fig. 22, using the values suggested by Hogentogler (27).

Peat bulk density = 80 lb per cu. ft.

a for peat = 4°. Hence A = 43°.

c for peat (cohesion) = zero.

w for well consolidated chalk fill assumed at 120 lb/cu. ft.

b the effective half-width of bank = 26·6 ft.

Hence

p = 369 lb per sq. ft + 1·328 K lb per sq. ft.

Fill pressure = $11{\cdot}5 \times 120$ = 1,380 lb per sq. ft.

For stability then :

p = 1,380 = 369 + 1·328 K lb per sq. ft.

whence K = 762 lb per sq. ft.

= the counterweight required for stability.

Actually on this particular site the peat bulged by 7·5 minus 2·5 = 5 ft.

Hence resistance by bulged peat = 5×80 = 400 lb per sq. ft.

Thus extra counterweight wanted = 762 minus 400 = 362 lb per sq. ft.

i.e., a counterweight of chalk of net depth required of $\frac{362}{120} = \underline{3\text{ ft.}}$

Actually the cable reserve chalk placed over the bulged peat averaged <u>4·5 ft.</u>

It would appear, therefore, that a reasonable estimate could be made as to probable conditions, and it is interesting to record that, to date, no further signs of settlement have been observed under current loadings. Strictly, the superimposed live loads have to be taken into account as well, and in counterweighting, therefore, something extra has to be allowed for stability, consequently the extra 1·5 ft of counterweight fill.

The matter of what type of road to place on the given subgrade requires careful consideration. Fig. 22*b* shows pressure distributions through various types of road surface (25), and brings out clearly the possible differences in intensity of loading on sub-grade through different materials.

Main sub-grade considerations which influence the design of roads are :—

(1) Actual constituents of subgrade or fill, e.g. sand, clay, etc. How the properties of a soil may be affected by the presence of constituents like mica is brought out in Fig. 22*a* where it is concluded that "a high voids ratio, high expansibility and high compressibility are largely due to the presence of flat grains in the soil" (26).

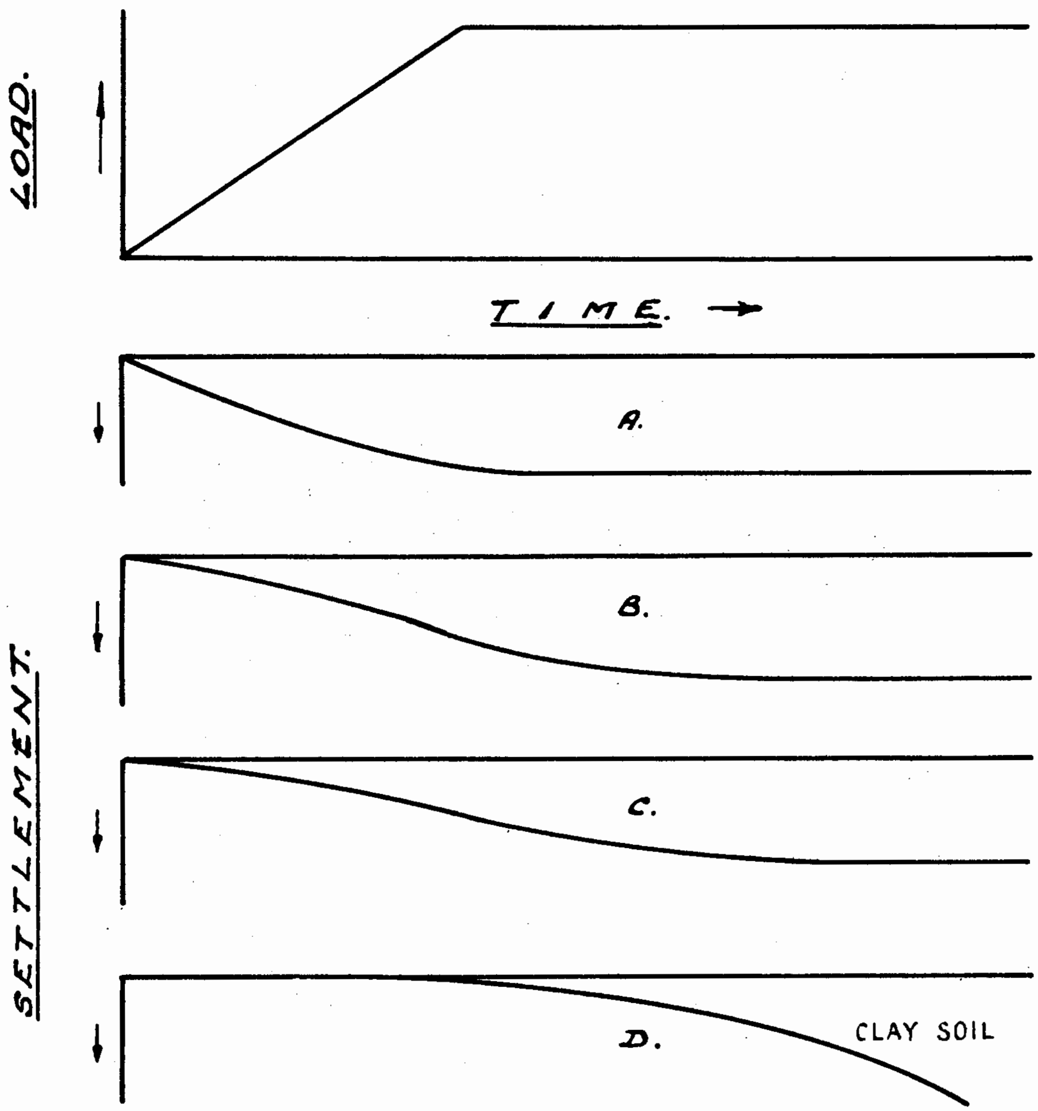


FIG. 18

LOAD-TIME-SETTLEMENT CURVES
AS OBSERVED AND CLASSIFIED BY TERSAGHI

FROM.........(26)

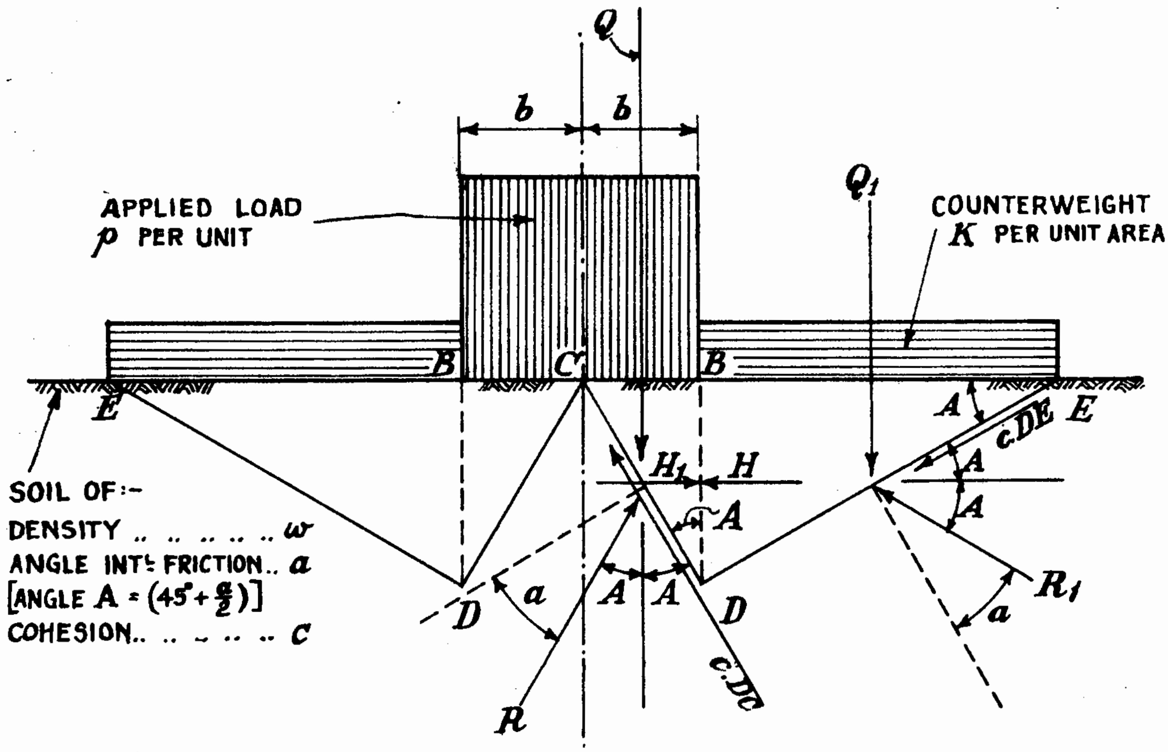


FIG. 19

DIAGRAM SHOWING TERSAGHI'S METHOD FOR DERIVING THE SOIL STABILITY FORMULA:-

$$p = \text{ULTIMATE BEARING CAPACITY}$$

$$= \frac{b\omega(1-\tan^4 A)}{2\tan^5 A} + \frac{K}{\tan^4 A} + \frac{2c}{\tan A \cdot \sin^2 A}$$

FROM..........(25)

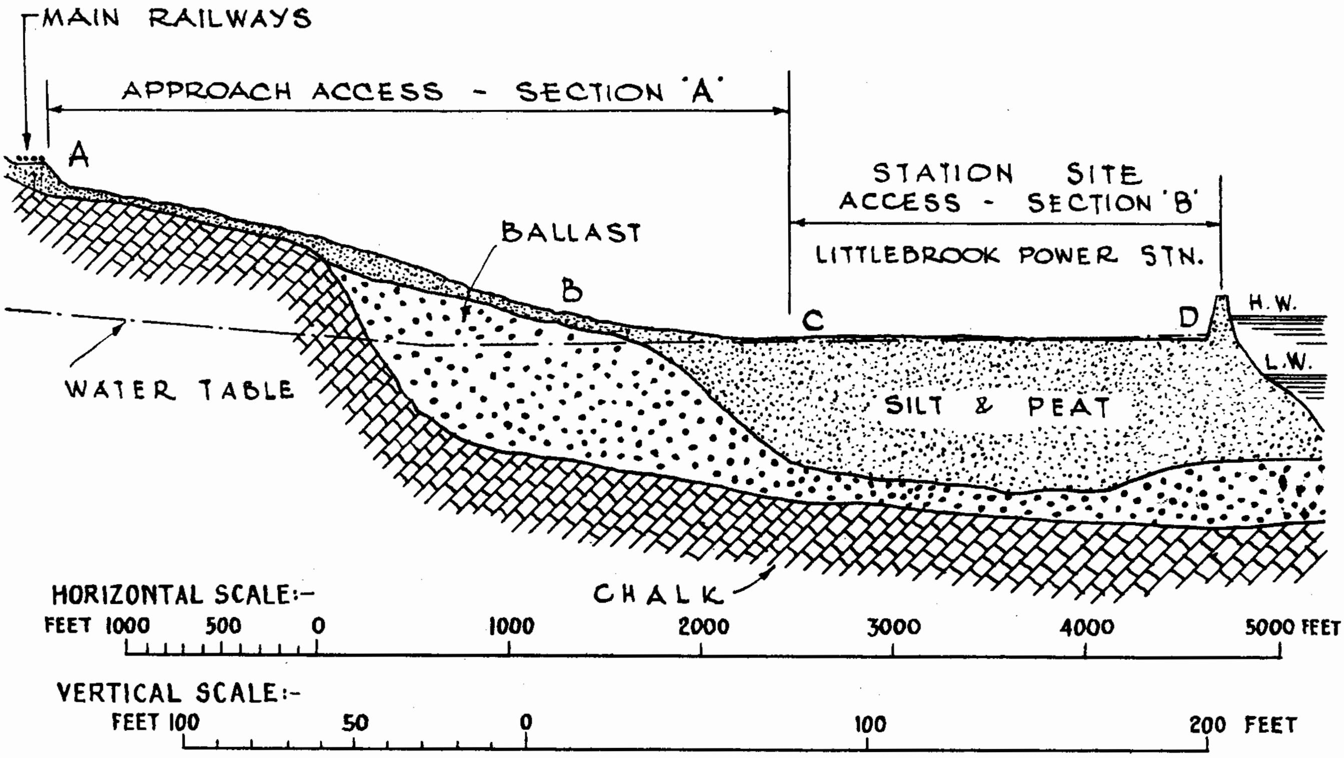


FIG. 20

TYPICAL HYDRO-GEOLOGICAL SECTION ALONG ACCESS APPROACH
LITTLEBROOK POWER STATION
KENT ELECTRIC POWER COMPANY

BY COURTESY OF SIR ALEXANDER GIBB & PARTNERS

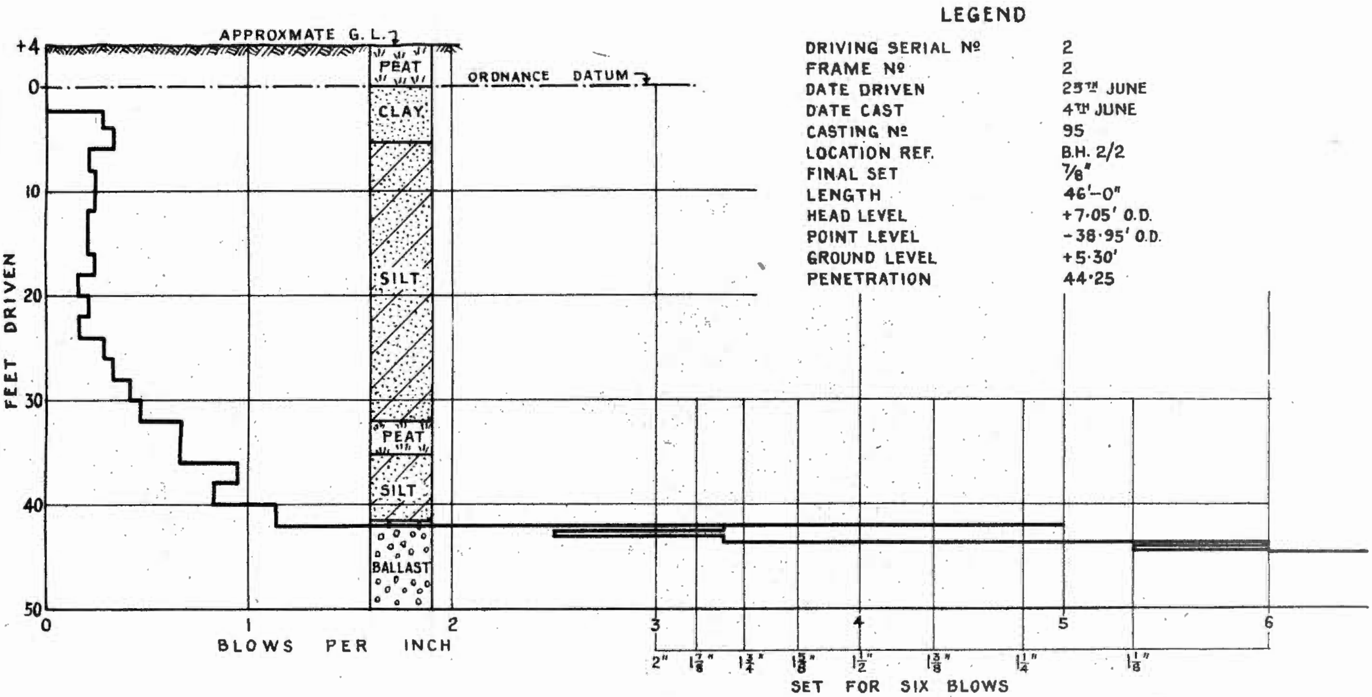
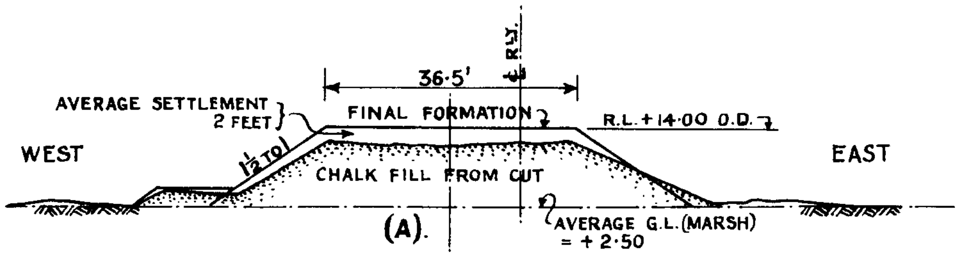


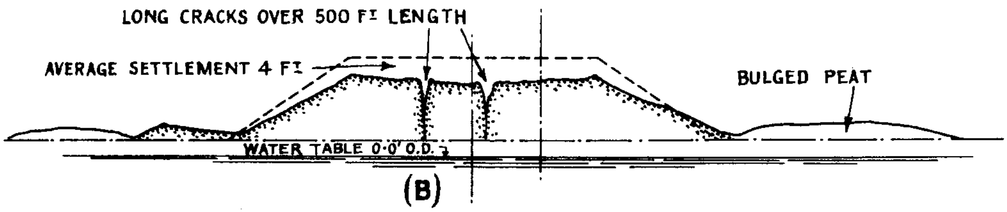
FIG. 21

TYPICAL DRIVING RECORD FOR 18"×18" R.C. PILE Nº B.H. 2/2
LITTLEBROOK POWER STATION
KENT ELECTRIC POWER COMPANY

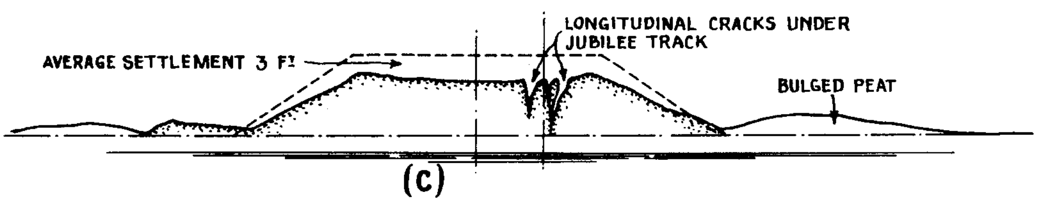
BY COURTESY OF SIR ALEXANDER GIBB & PARTNERS



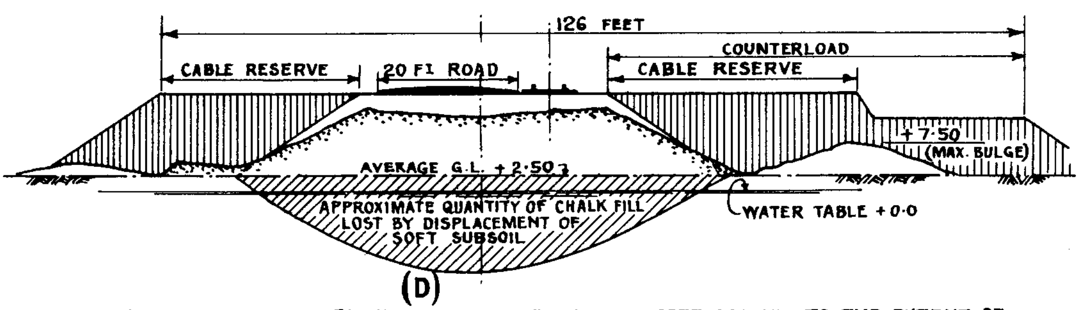
STAGE 1. EMBANKMENT BROUGHT TO CORRECT FORMATION LEVEL, USING A 10 TON ROLLER, BY END OF JULY 1937. BY 1ST SEPTEMBER, SETTLEMENT, AVERAGING 2 FEET HAD OCCURRED, AS SHEWN.



STAGE 2. EMBANKMENT BROUGHT TO FORMATION AGAIN AND STEAMROLLED. SETTLEMENT OCCURRED, IN PLACES UP TO 9 INCHES PER DAY. LONGITUDINAL CRACKS DEVELOPED OVER A LENGTH OF 500 FEET, AND AT THE SAME TIME THE BULGING OF THE PEAT, ADJACENT TO THE TOE OF THE BANK, WAS OBSERVED, AS SHEWN, TOTAL SETTLEMENT, BY END OF SEPTEMBER, WAS 4 FEET.



STAGE 3. EMBANKMENT BROUGHT BACK TO FORMATION AND ROLLED. BY MID-OCTOBER FURTHER SETTLEMENT, TO THE EXTENT OF 3 FEET HAD TAKEN PLACE, AND LONGITUDINAL CRACKS, SIMILAR TO THOSE SHEWN FOR STAGE 2, HAD DEVELOPED. BULGING OF THE PEAT HAD INCREASED. RATE OF SETTLEMENT HAD SLOWED DOWN TO LESS THAN 1 INCH PER DAY.



STAGE 4. BANK BROUGHT TO FORMATION AND ROLLED. SETTLEMENT, TO THE EXTENT OF 3 FEET OCCURRED. AS IT WAS NECESSARY TO HAVE ROAD AND RAIL ACCESS ESTABLISHED BY MID-NOVEMBER, THE BULGED PEAT ON EITHER SIDE OF THE BANK WAS COUNTERLOADED WITH EXTRA FILL AS SHEWN. ROAD AND RAILWAY WAS COMPLETED. ALTHOUGH IT HAS BEEN NECESSARY, IN THE PERIOD 1937-1942, TO PACK UP THE RAILWAY TO MAKE UP FOR SETTLEMENT, THE MACADAM ROAD HAS SHEWN NO SIGNS OF FAILURE.

FIG. 22

ACTUAL SETTLEMENTS OBSERVED DURING THE CONSTRUCTION OF THE MAIN ROAD AND RAIL ACCESS EMBANKMENTS AT LITTLEBROOK POWER STATION (KENT ELECTRIC POWER COMPANY) SITUATED ON A MARSH SITE ON THE SOUTH BANK OF THE THAMES

BY COURTESY OF SIR ALEXANDER GIBB & PARTNERS.

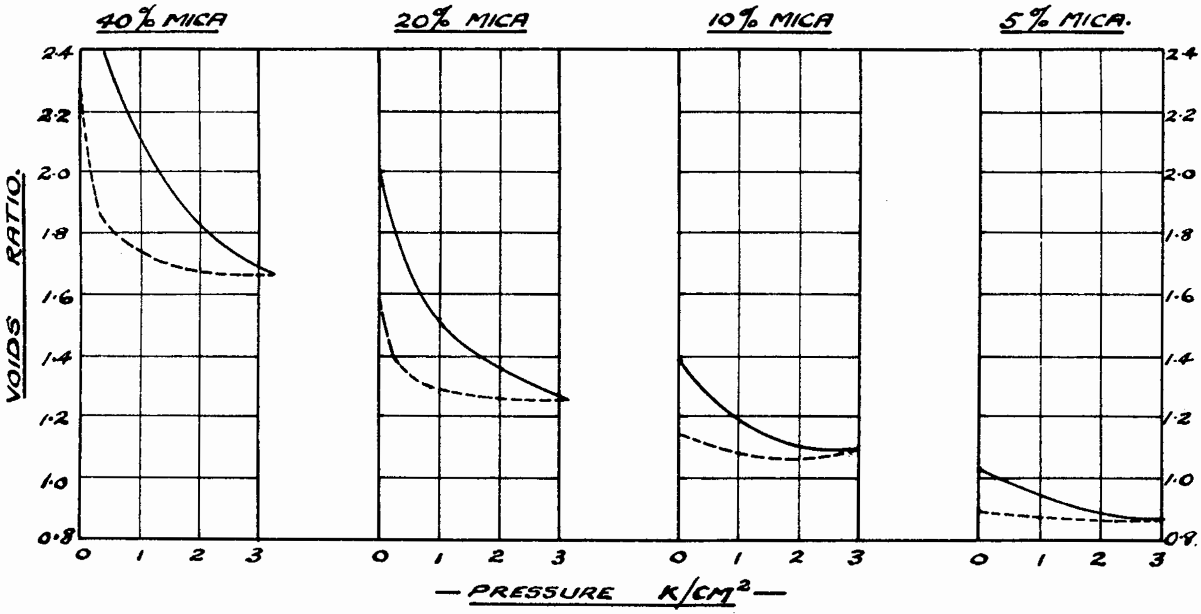


FIG. 22A

TESTS ON DRY NON-COHESIVE SAND-MICA MIXTURES INDICATING THAT "A HIGH VOIDS RATIO, HIGH EXPANSIBILITY AND HIGH COMPRESSIBILITY ARE LARGELY DUE TO THE PRESENCE OF FLAT GRAINS IN THE SOIL"

FROM..........(26).

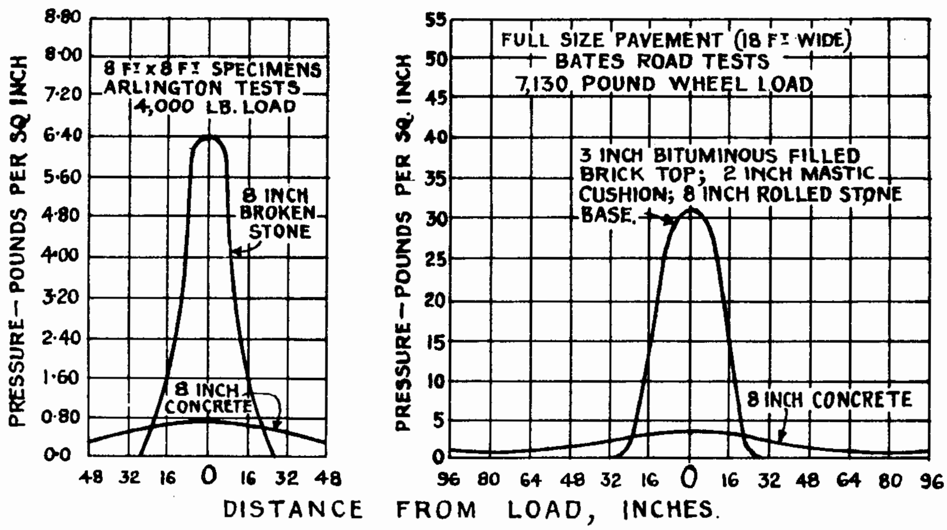


FIG. 22B

PRESSURE DISTRIBUTION THROUGH VARIOUS TYPES OF ROAD SURFACES

FROM.........(25)

(2) The density and degree of compaction of the soil.

(3) Physical characteristics such as shrinkage, expansion, plasticity, elasticity, permeability, etc.

(4) Prevailing climate, e.g. whether temperatures vary to extremes, and whether frost action is possible.

(5) Level of water table and whether it is constant or varies.

(6) Type, weight, quantity of traffic loading, and whether traffic consolidation is possible.

For power sites it must be remembered that in addition to purely " heavy " loads carried on rubber-tyred scammells, there will always be mobile cranes, bull-dozers, etc., on caterpillar tracks, and it is no use designing roads which would be torn up or damaged by the passage of such vehicles.

CHAPTER IV

THE COOLING WATER CIRCUIT

The large quantities of cooling water required by modern stations, operating at high vacuum, make the cooling water circuit of considerable importance, the pumps, motors and pipes, etc., required, being the largest of auxiliary plant. Thus cooling water is often a limiting factor in locating power stations and a prime consideration in planning extensions.

The following practical examples emphasise the point :—

Fulham Power Station (9)

Estimated requirements for a generating capacity of 310 mW amounted to 14·5 million gallons per hour, taking into account raw water requirements for evaporators, sealing water for pump glands, and auxiliary services.

The quantity required solely for condensing purposes for a 60 mW set, 29 in. vacuum with barometer 30 in. mercury, average river water temperature 55°F., is approximately 2·5 million gallons per hour.

Battersea Power Station (15)

Estimated requirements for three 80,000 kVA units was 16·5 million gallons per hour (735 cusecs).

The cost importance of the circuit may be seen from Tables 5 and 6.

A simple example illustrates the importance of maintaining or increasing vacuum :—

Referring to the *Mechanical World Year Book*, 1936 (28), it is noted that by increasing vacuum from 28 in to 28·5 in a saving of 15 B.Th.U. results.

Assume a 30 mW unit, steaming at, say, M.E.R. of 24 mW, for which the Willans line shows a steam consumption of 217,000 lb per hour, and coal of 12,000 B.Th.U. per lb, efficiency 80 per cent,

$$\text{Net coal saving : } \frac{217{,}000 \times 15}{12{,}000 \times \cdot 80} = 340 \text{ lbs/hr.}$$

For 60 per cent plant factor (at this rate), coal saving amounts to :—

$$\frac{340 \times 0{\cdot}6 \times 8{,}760}{2{,}240} = 800 \text{ tons per annum.}$$

With price of coal as fed into Fulham bunkers (9) at 7·25d. per million B.Th.U. :—

$$\text{Cost of saving : £}\ \frac{800 \times 2{,}240 \times 12{,}000 \times 7{\cdot}25}{1{,}000{,}000 \times 240} = \text{£650 per annum.}$$

Reckoning interest at 5·5 per cent, this would justify an incremental capital investment of £11,800.

Table 8 shows the economic ranges of vacua recommended (29) based on the average annual cooling water temperatures prevailing :—

TABLE 8

ECONOMIC VACUA FOR DIFFERENT RANGES OF TEMPERATURE (28)

Average Temp. in °F.		50	55	60	65	70	75	80	85	90
Vac. ins. Hg.	From	28·85	28·70	28·55	28·4	28·2	27·9	27·6	27·3	27·0
	To	29·25	29·10	28·95	28·8	28·6	28·3	28·0	27·7	27·4

Where river water is not sufficient to supply cooling water demands, cooling towers may be resorted to. Sundry objections to this method may be found in :—

(1) The higher cooling water inlet temperatures which result, and consequent lower vacuum for economic operation.

Table 9 shows typical figures for a 30 mW M.C.R. set.

TABLE 9 (13)

***COMPARISON OF COOLING WATER SYSTEMS**

System	C.W. G.P.M.	C.W. °F.	Vacuum Ins. Hg. Bar. 30	Condenser Cooling Surface Sq. ft.
River water	20,000	55–60	29 in to 28·8 in	25,000
Cooling towers	27,500	80	28	29,000

*(Obviously for United Kingdom conditions.)

(2) It is a difficult matter to avoid " dwarfing " a station with these installations.

(3) Unless well designed and carefully operated, spray may result, giving rise to complaints from neighbours.

Obvious advantages lie in the small amount of make-up water required, estimated by Carr (13) as about 0·5 gallons per hour/kW, and the fact that sewage effluent may be used for this purpose.

For the purpose of this work only the River (Sea) Water system will be looked into. The works may be sub-divided to taste. Thus :—

(1) The main resistance—or condenser.

(2) The conduits and buspipes, in and out.

(3) The pumps.

(4) The intake and outlet works.

Nearly all large installations make use of the siphon principle, thus ensuring that pumping will be dependent on friction only, and requiring that pumps and outlet be drowned at all times. This has an influence on the placing of the condensers, which have to be situated low enough to make siphonage possible, having regard to excavation costs.

1. The Condenser Problems.

The trend for modern stations is to specify condensers of the two- or three-pass, twin-shell type, with two or four connections to the buspipes. The twin-shell arrangement allows for shutting down one half of the condenser for cleaning purposes without outing the machine, so assuring continuity of service.

The condensers are usually mounted on small stools, set between the main turbo-alternator foundation blocks, and carried on springs so as to prevent undue weight coming on to the exhaust flange of the turbines. The foundation problems therefore present no special difficulty to the civil engineer. See Fig. 23.

His main concerns are :—

(*a*) The quantity of cooling water required for the performance of duties specified.

(*b*) The friction resulting from (*a*).

(*c*) The depths of excavation required in the turbine house for maintenance of siphonage

The quantities of cooling water required under given conditions are usually specified. Nevertheless—as operating conditions can never be represented by simple curves and straight lines, but tend to vary over a " range " between extremes—civil engineers should be familiar with the principles of obtaining the specified data, and with the practical conditions prevailing on such sites.

Guy and Winstanley have shown in a paper before the Institution of Mechanical Engineers (20) that an appreciable error may result from the arbitrary assumption that the heat rejected to the cooling water is 1,000 B.Th.U. per lb steam condensed. This is due to the fact that steam supplied to such condensers in practice is rarely dry.

Kaula and Robinson came to a similar conclusion (19) when they held that : " taking the heat rejected to cooling water as equivalent to the latent heat of steam, we commit an error of fair magnitude, the real objection to which lies in the fact that the error is a variable one."

Guy and Winstanley's formula for heat rejected to cooling water is (20) :—

$$H = h_1 - \frac{2545}{D.\,n.} - h_4 \text{ B.Th.U. per lb.}$$

where h_1 = total heat at stop valve to prime mover in B.Th.U. per lb.

D = Steam consumption in lb per *brake h.p.*

n = Mechanical efficiency of prime mover (98-99 per cent for large machines).

h_4 = The sensible heat of the condensate in B.Th.U.'s per lb,

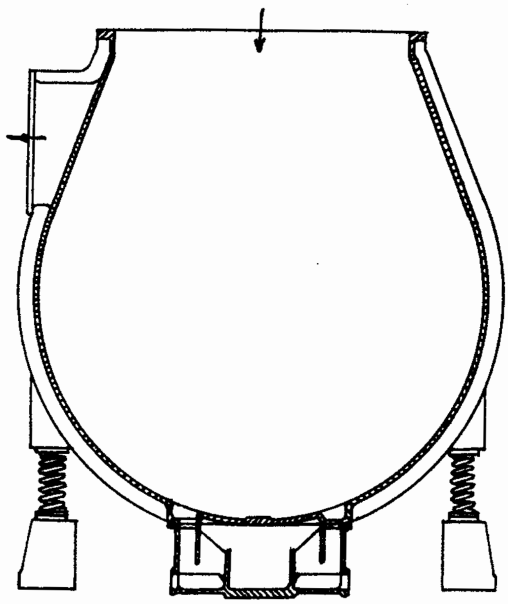


FIG. 23

SKETCH SHEWING ONE TYPICAL METHOD OF CONDENSER MOUNTING and holds for systems fitted with air ejectors as well as for complicated regenerative feed-heating, providing, in both cases, that D includes both the steam for the ejector and that condensed in the regenerative feed-heater, and that h_4 is the sensible heat of the condensate after the ejector heater or the last regenerative feed-heater, as the case may be.

Then Q = Cooling water required

$$= \frac{H.\,w}{600\,(t_2 - t_1)} \text{ g.p.m.}$$

where w = lb steam per hour from Willans lines or steam rate curves.

t_2 = outlet cooling water temperature.

t_1 = inlet cooling water temperature.

Guy and Winstanley further conclude that the mean temperature difference across the condenser, for two- and three-pass units, is represented more accurately by the " arithmetic mean " formula than by the " Grashof" formula.

t_1 is fixed by site conditions, and has an annual variation, unless recirculation occurs, whilst t_2 depends on a number of factors such as cooling surface provided, quantity of water, velocity of water in tubes, state of tubes, steam temperature, etc.

From typical steam consumption characteristic curves for 30 and 60 mW sets respectively, as shown in Figs. 24 and 25, it is possible to construct " Willans " lines for total steam used as shown in Figs. 26 and 27. And hence, with assumptions or given data as noted, it is possible to construct theoretical cooling water characteristic curves as shown. (Figs. 26 and 27.)

In practice, however, it is not possible to provide pumps which could supply water " on tap " as required by such curves. By installing pumps of fixed capacities a compromise is effected and the cooling water temperature across the condenser varies somewhat as shown in Figs. 28a and b, which was obtained from tests carried out at Littlebrook Power Station. Practical characteristics obtained for such an installation come out as shown in Fig. 29a, from which it is possible to see how pump sizes and groupings are related to requirements. (See also Fig. 29b.)

Estimates for cooling water requirements must allow for requirements for fire services, high or low pressure sluicing water, and sealing water for pump glands. The take-offs for such pipes are located upstream of the condenser to make use of the pressure head available for the priming of pumps. The diversity factor as regards demand, and the fact that it is extremely unlikely that all other demands would be a maximum when cooling water requirements are maximum, make it unnecessary for large extra water allowances to be made.

Once an idea has been formed of the water quantities to be handled, it is possible to estimate, from the given condenser data, the friction head lost through the condenser.

Guy and Winstanley recommend the following formula (20) :—

$$H = n\left(C_1 \frac{L.}{D} \frac{Vt^2}{2g} + C_2 \frac{Vt^2}{2g.}\right) + 1{\cdot}0 \frac{Vb^2}{2g} = \text{feet head.}$$

where n = Number of passes,

L = Length of tubes in feet,

D = Diameter of tube in feet,

Vt = Mean velocity of water through tube in feet per second,
Vb = Ditto through outlet branches of water-box,
C_1 = Constant for the tubes,
C_2 = Constant for exit and entry losses of tubes.

Fig. 30 shows results of their tests to determine values for these constants, and Fig. 31 shows correction values to be applied to the constants for conditions varying from the basis of: 5 ft per sec; mean c.w. temperature 70°F., $\frac{3}{4}$ in o/s dia, 18 I.W.G. for the tubes.

When applying this formula to full-scale tests carried out, for one shell of a 30,000 kW unit, at Littlebrook Power Station, a reasonable approximation to measured values was obtained, and if full allowance was made for the "state" of the tubes, by suitably increasing C_1 more exact values could have been determined for friction head. Thus :—

Condenser Specification

Number of passes ....(n) = 3
Total number of tubes per shell.................. = 3,583
D (for 1 in. o/s 18 I.W.G. tubes)............... = 0·0754 ft
Length of tubes .... (L) = 17 ft

Pitometer Measurements

Q measured (per shell) ....= 37 cusecs, giving :—
Vt ....= 6·97 ft per sec
Vb .... = 9·31 ft per sec

C_1 and C_2 from Fig. 30, assuming tubes with bell-mouthed inlet, ferruled outlet, were taken as 0·023 and 1·27 respectively, making *no* allowance for dirty state. C_1 was corrected for operating conditions using Fig. 31.

The measured heads shown in Table 10 were extremes obtained

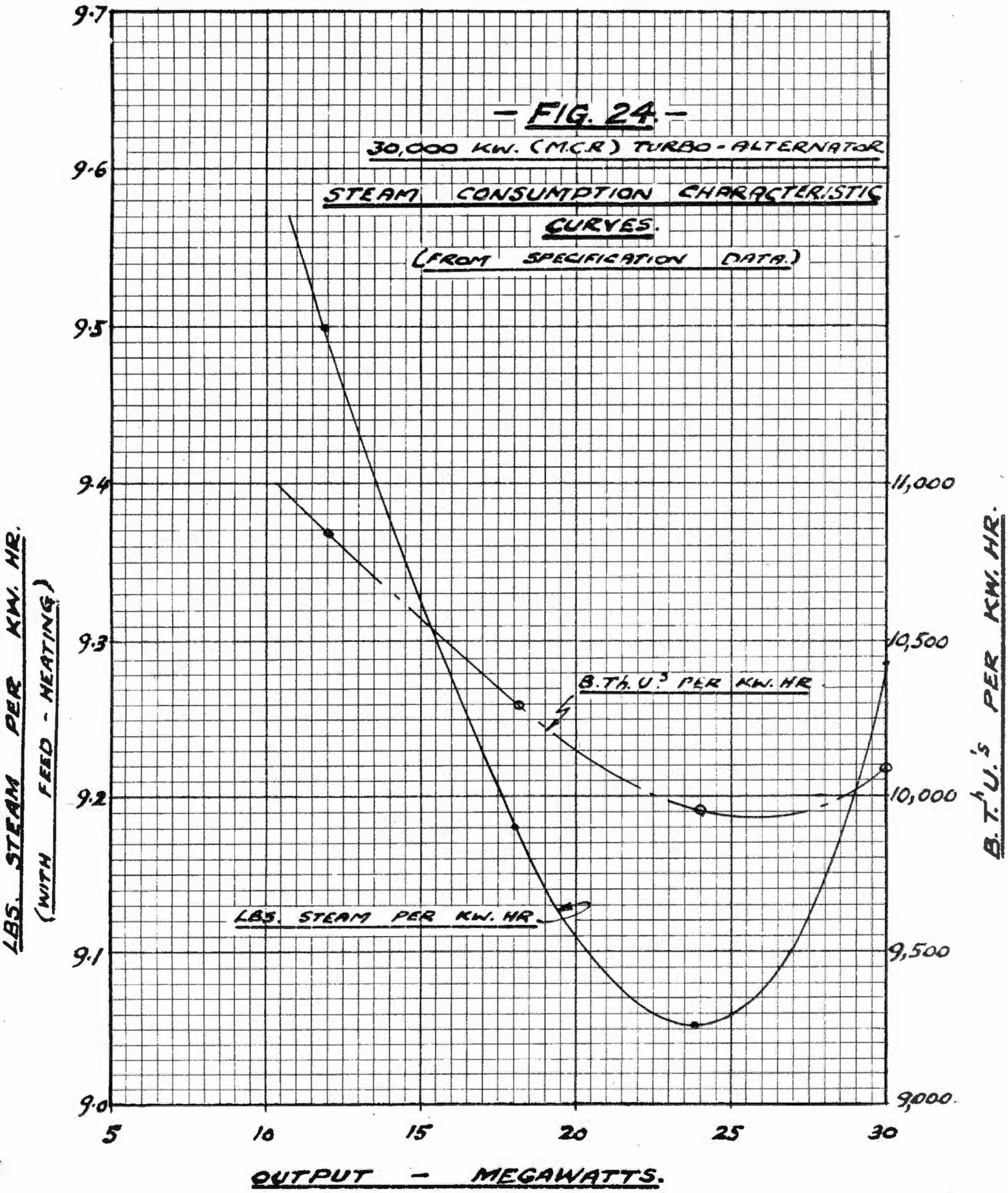
TABLE 10

TESTS CARRIED OUT AT LITTLEBROOK "A" POWER STATION ON CONDENSER SHELL (30,000 kW UNIT) TO OBTAIN HEAD LOST.

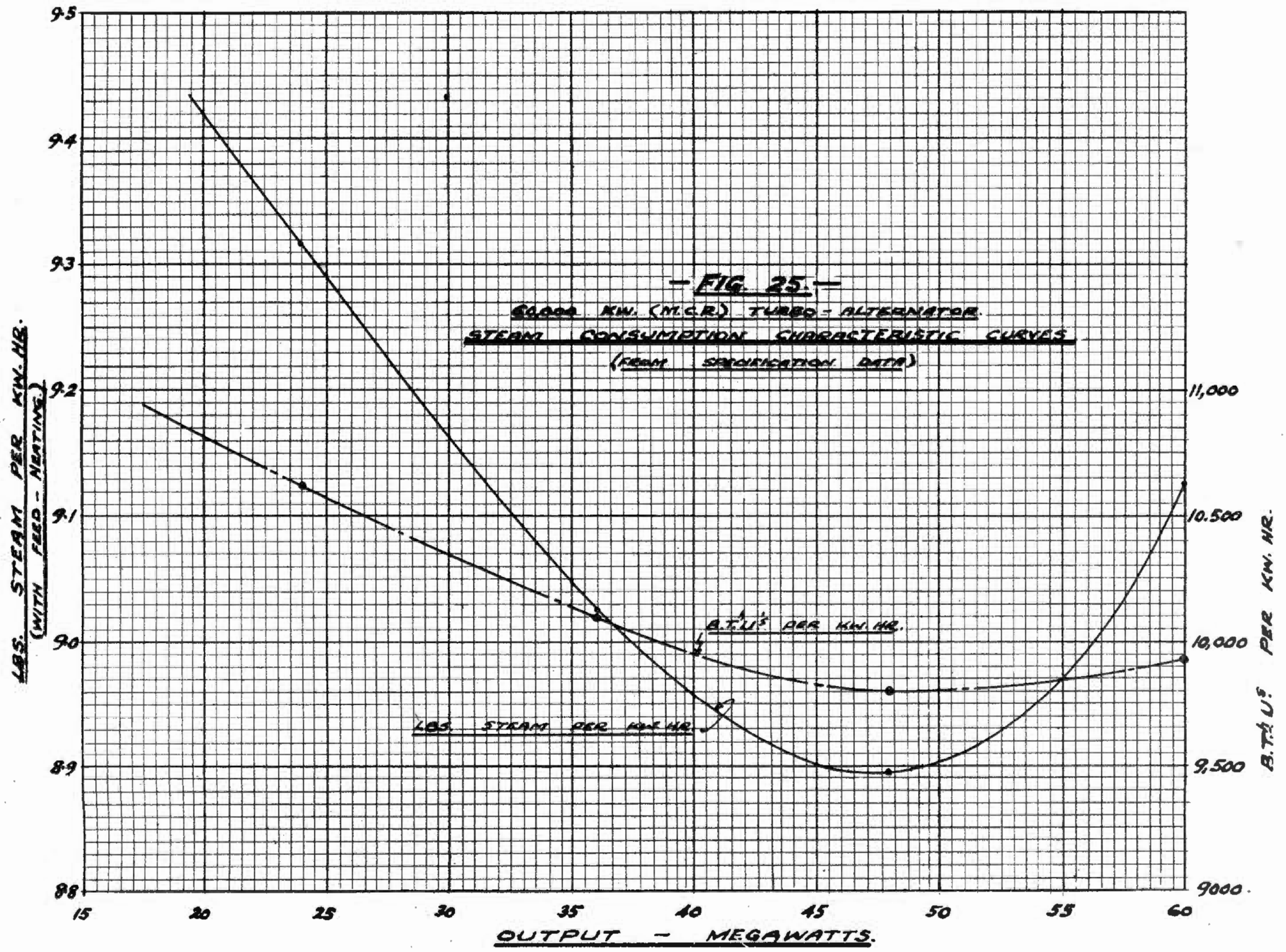
FORMULA USED

$$H = n\left(C_1\frac{L}{D}\cdot\frac{Vt^2}{2g} + C_2\frac{Vt^2}{2g}\right) + \frac{Vb^2}{2g}$$

mW Generated	Measured Head Lost Ft	Mean Head Lost	Cooling Water			Calculated Head Lost Ft
			t_1 °F.	t_2 °F.	Mean t = °F.	
27·5 28·0	14·75 17·40	16·07	67·0 67·5	77·0 76·0	72·0 71·7	14·27



- FIG. 24 -
30,000 KW. (M.C.R) TURBO-ALTERNATOR
STEAM CONSUMPTION CHARACTERISTIC CURVES.
(FROM SPECIFICATION DATA.)
B.Th.U.s PER KW. HR.
LBS. STEAM PER KW. HR.
9.7
9.6
9.5
9.4
9.3
9.2
9.1
9.0
11,000
10,500
10,000
9,500
9,000
5
10
15
20
25
30
LBS. STEAM PER KW. HR.
(WITH FEED - HEATING)
B.T.h.U.'s PER KW. HR.
(WITH FEED - HEATING.)
OUTPUT - MEGAWATTS.



- FIG. 25. -
60,000 KW. (M.C.R.) TURBO - ALTERNATOR.
STEAM CONSUMPTION CHARACTERISTIC CURVES
(FROM SPECIFICATION DATA)
B.T.U's PER KW. HR.
LBS. STEAM PER KW. HR.
LBS. STEAM PER KW. HR.
(WITH FEED - HEATING)
B.T.U's PER KW. HR.
OUTPUT - MEGAWATTS.
9.5
9.4
9.3
9.2
9.1
9.0
8.9
8.8
11,000
10.500
10,000
9,500
9000
15
20
25
30
35
40
45
50
55
60

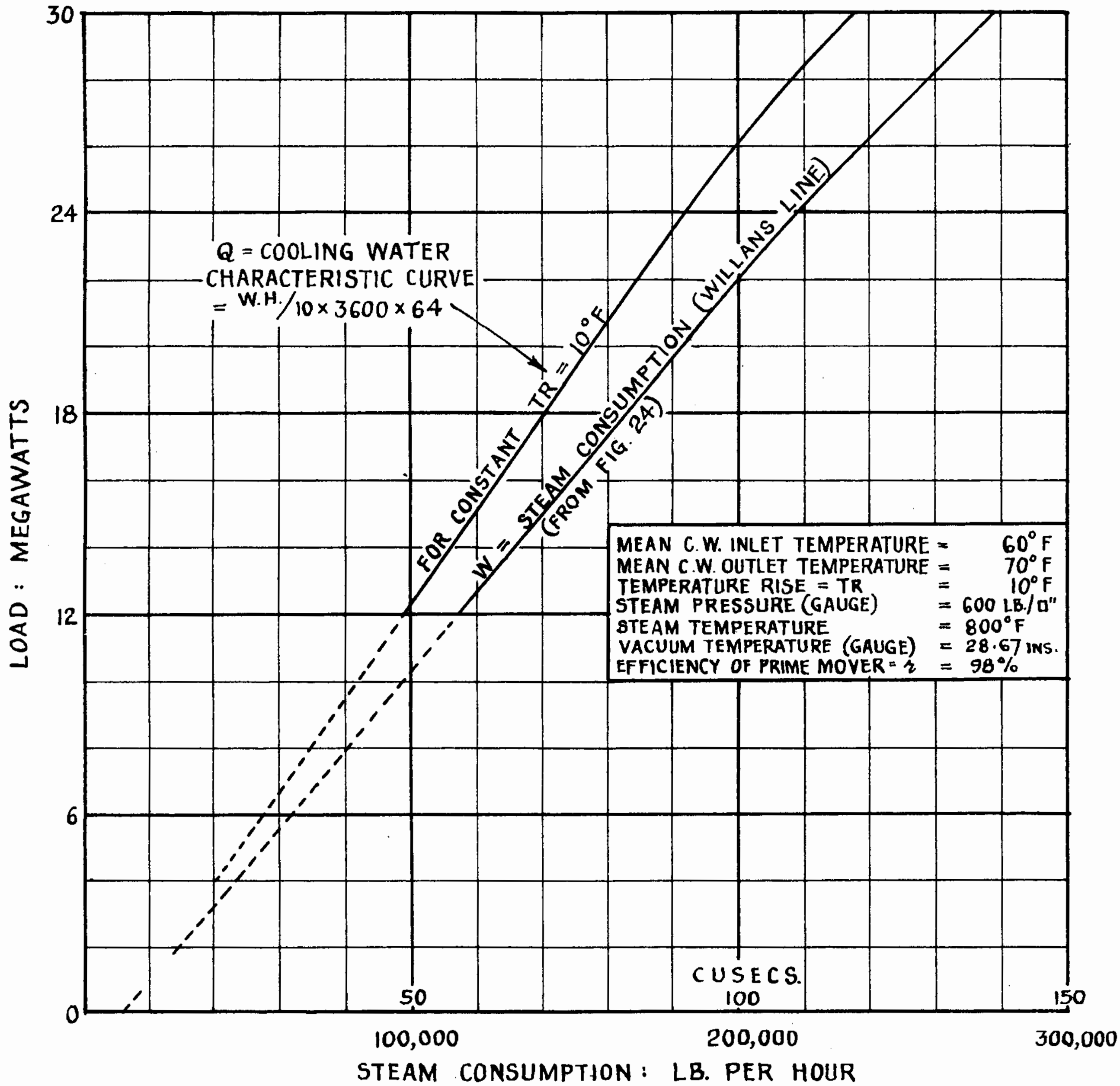


FIG. 26

STEAM CONSUMPTION AND THEORETICAL COOLING WATER CHARACTERISTIC CURVES: 30,000 KW. SET

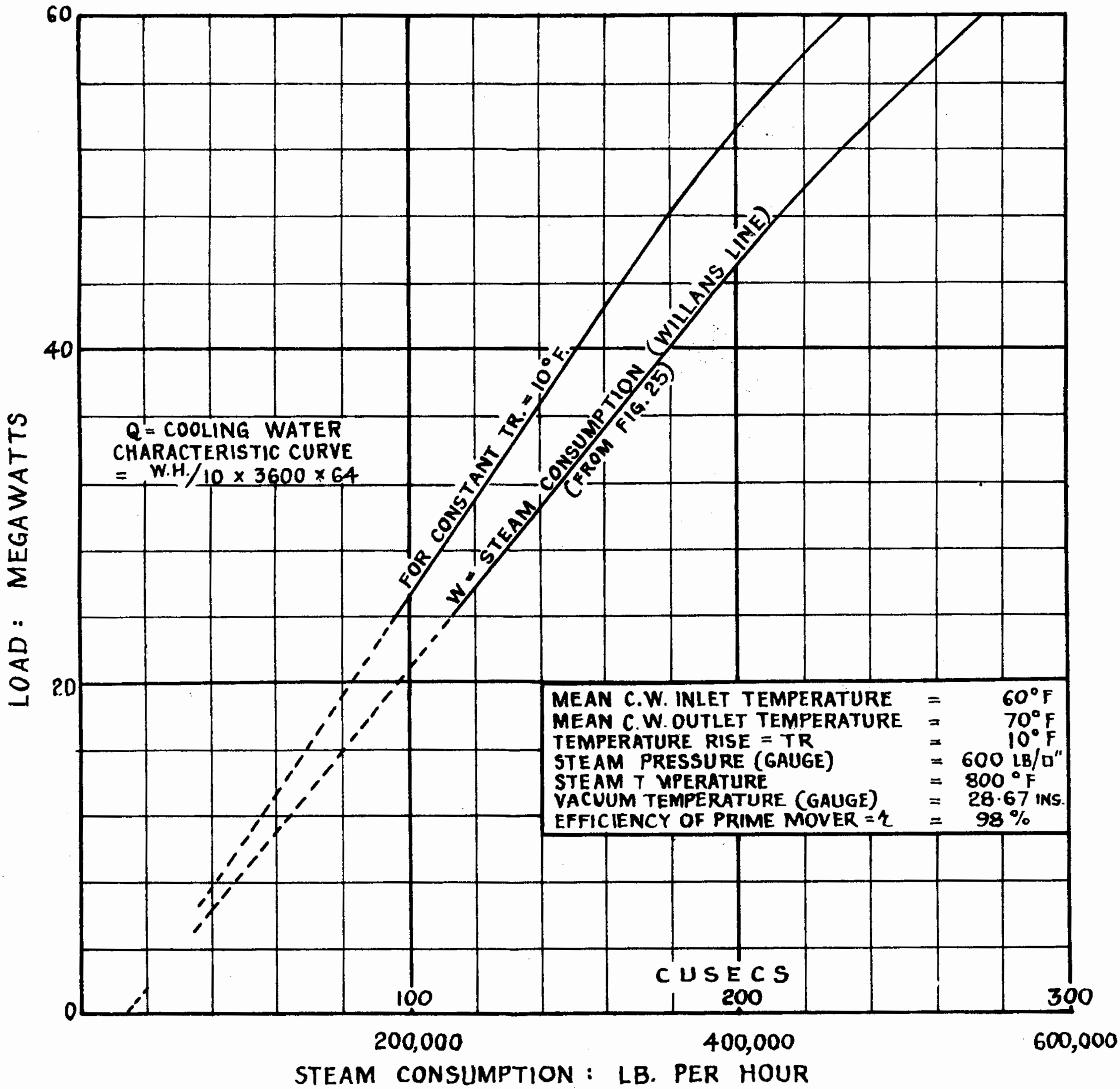
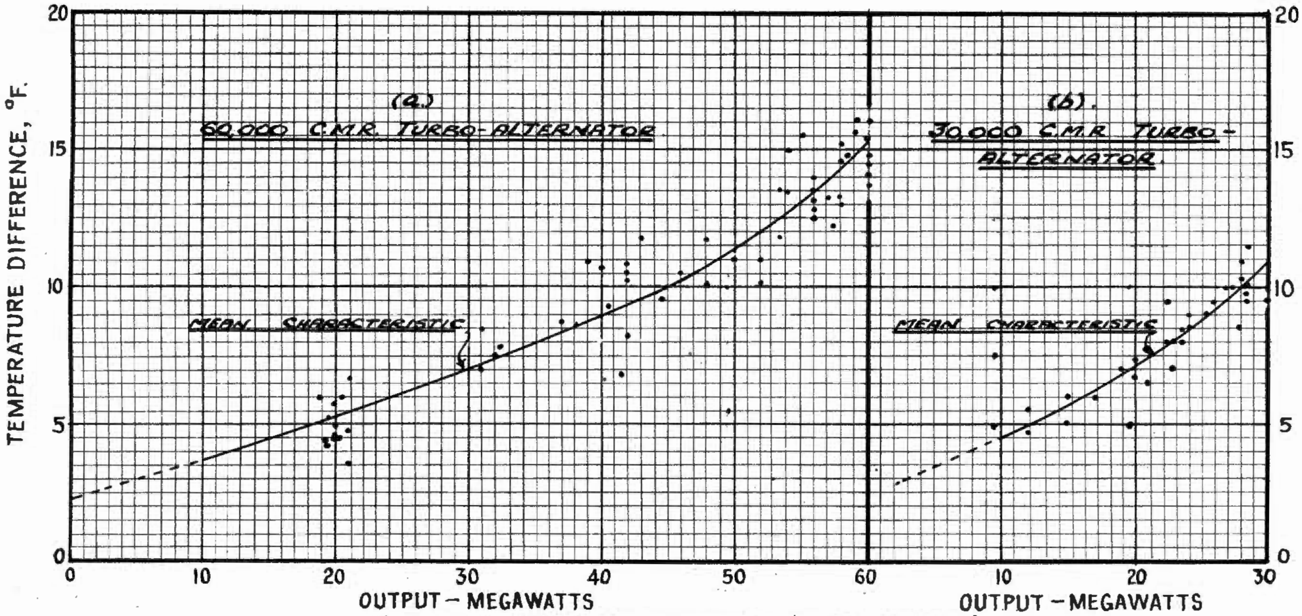


FIG. 27

STEAM CONSUMPTION AND THEORETICAL COOLING WATER CHARACTERISTIC CURVES: 60,000 KW. SET



(FOR CONDENSER AND PUMP SPECIFICATIONS SEE FIGS. 45 AND 47)

FIG. 28

COOLING WATER TEMPERATURE DIFFERENCE CHARACTERISTIC CURVES

($T_r = T_2 - T_1$)

OBSERVED AT LITTLEBROOK POWER STATION, KENT ELECTRIC POWER C°

(BY COURTESY OF SIR ALEXANDER GIBB & PARTNERS)

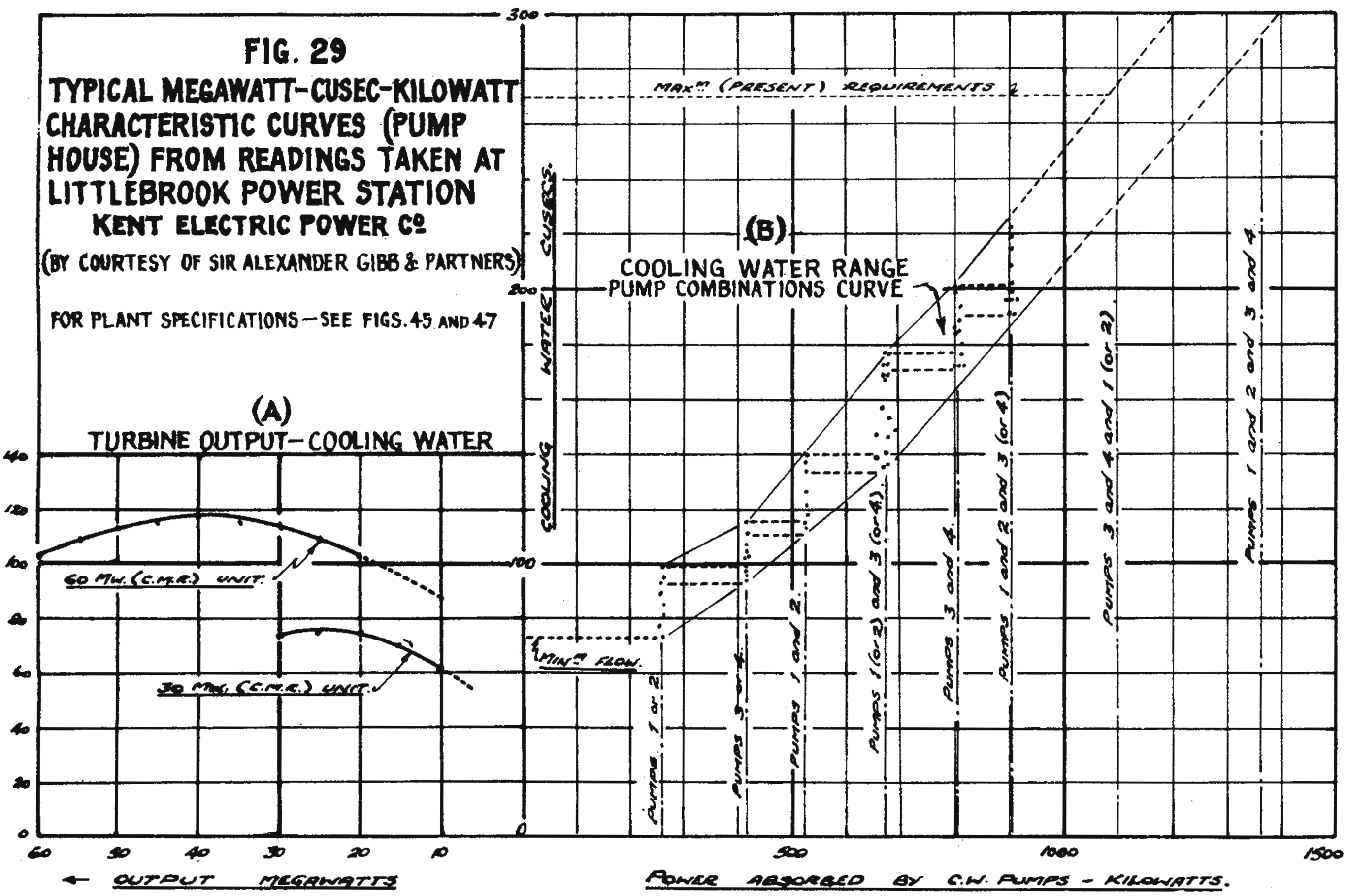


FIG. 29
TYPICAL MEGAWATT-CUSEC-KILOWATT CHARACTERISTIC CURVES (PUMP HOUSE) FROM READINGS TAKEN AT LITTLEBROOK POWER STATION
KENT ELECTRIC POWER Co
(BY COURTESY OF SIR ALEXANDER GIBB & PARTNERS)
FOR PLANT SPECIFICATIONS — SEE FIGS. 45 AND 47
(A)
TURBINE OUTPUT — COOLING WATER
60 MW. (C.M.R.) UNIT.
30 MW. (C.M.R.) UNIT.
← OUTPUT MEGAWATTS
(B)
COOLING WATER RANGE
PUMP COMBINATIONS CURVE
COOLING WATER CUSECS.
MAXm (PRESENT) REQUIREMENTS
MINm FLOW.
PUMPS 1 or 2
PUMPS 3 or 4
PUMPS 1 and 2
PUMPS 1 (or 2) and 3 (or 4)
PUMPS 3 and 4
PUMPS 1 and 2 and 3 (or 4)
PUMPS 3 and 4 and 1 (or 2)
PUMPS 1 and 2 and 3 and 4
POWER ABSORBED BY C.W. PUMPS - KILOWATTS.

$$H = n\left(C_1 \frac{L}{D} \cdot \frac{Vt^2}{2g} + C_2 \frac{Vt^2}{2g}\right) + 1{\cdot}0 \frac{Vb^2}{2g}$$

TUBE OUTSIDE DIA. AND GAUGE	FIXING	C_1 AT 70 DEGREES F. AND 5 FEET PER SEC.	C_2
$\frac{3}{4}$ INCH 18 I.W.G.	→	0·02416	1·60
	→	0·02508	1·23
	→	0·02496	0·95
1 INCH 18 I.W.G.	→	0·02290	1·48
	→	0·02307	1·27
	→	0·02301	1·03

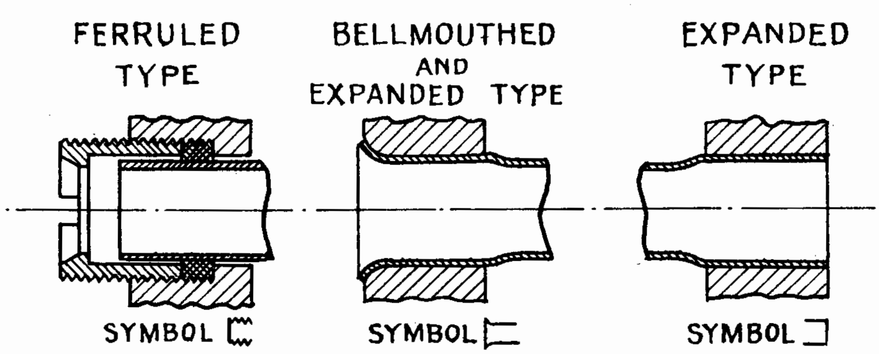


FIG. 30

RESULTS OF TESTS TO DETERMINE FRICTION COEFFICIENTS FOR DIFFERENT TYPES OF CONDENSER TUBE FIXING

(FROM....... 20)

BASIS: 5 FT. PER SEC.; 70°F; TUBES 3/4 INS. OUTSIDE DIAMETER AND 18 I.W.G.

OUT. DIAM INS	THICKNESS I.W.G.	FACTOR C_4.	OUT. DIA. INS.	THICKNESS I.W.G.	FACTOR C_4.
5/8	16	1·067	7/8	16	0·971
	18	1·055		17	0·965
	19	1·049		18	0·959
				19	0·953
3/4	14	1·024	1	16	0·936
	16	1·012		17	0·930
	18	1·000		18	0·924
	19	0·994		19	0·918

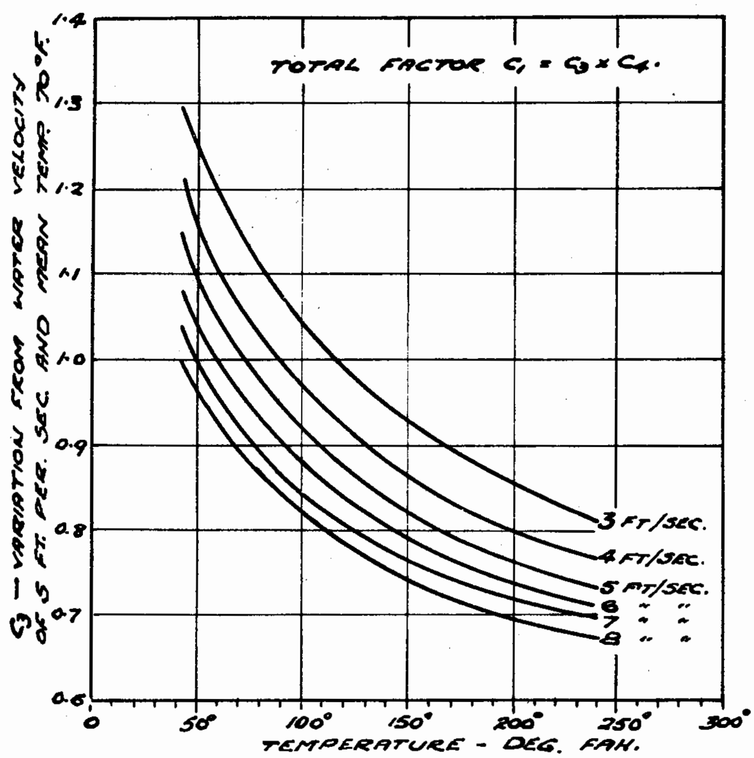


FIG. 31

CORRECTION FACTORS FOR VARIATION IN WATER VELOCITY, MEAN TEMPERATURE AND TUBE SIZE OF SURFACE CONDENSERS

(FROM ....20)

2. Conduits and Bus Pipes—In and Out

The prime consideration is the provision of the most economical number of conduits of the best size to perform the hydraulic duties.

To illustrate the nature of the economy curves practical examples have been worked out for square concrete culverts, singly, and in banks, and the results are shown in Figs. 32 and 33.

In addition to the main assumptions stated on these curves, it was further assumed that a dense, impermeable mix was used, the stresses allowed being such as to give, as a reasonable wall thickness, after allowing for cover to reinforcement and for shear (for 60-ft head) :—

$$t = 1{\cdot}64\ d \text{ in. (where } d = \text{water width in feet).}$$

The reinforcing steel worked out at 7·95 lb per cu. ft. including for shrinkage steel at 0·4 per cent of concrete area.

Practical examples are :—

Barking Power Station .... 6·10 lb per cu. ft.
Littlebrook Power Station .... 6·45 lb per cu. ft.

In both the above cases, however, wall thickness was in excess of 1·64 d due to various causes, which would reduce steel per cu. ft. concrete.

Sundry conclusions, summarised from these curves are shown in Table 11.

TABLE II

COMPARISON OF TOTAL ANNUAL COSTS FOR ECONOMIC CULVERT SIZES DERIVED FROM FIGURES 32 AND 33 FOR SQUARE CONCRETE CULVERTS.

Type	Economic Width (Ft)	Total Cost: Shillings per annum per ft run
S.M.	6 ft 3 in	21·5
D.M.A.	Just under 4 ft 9 in	24·5
D.M.B.	Just over 4 ft 9 in	21·0

(S.M. = Single Main. D.M.A. = Double Main, Case A.)

Economic reasons alone do not constitute sufficient justification for the decision to construct, say, double mains as opposed to single mains. The fact that, with double mains one could be shut down for inspection and maintenance, whilst carrying on at half service, or even at full service with a temporary increase in operating cost, using the remaining main, is of importance, since it guarantees continuity of service. But the choice is not limited to double mains. Economic investigations should be pressed the whole length. There is the additional economy accruing from constructing " in banks " as opposed to separate mains—due to savings in excavation, back-filling and materials, not to mention the advantages of concentration of plant. Such savings can be represented approximately by the curve shown in Fig. 34, from which it appears that ultimate savings would approach the figure of 25 per cent asymptotically.

These remarks apply equally to banks of cable tunnels and banks of cable ducts.

This leads on to the question of " present worth of future savings," when one is considering whether to construct now for future extensions. An example may serve to illustrate the point :—

Assume we are considering whether to lay down two culverts now for an extension in five years' time—the economic sizes shown in Fig. 33 being considered. Then,

For separate mains
Fixed charges at 12 per cent .... = 18·7 shillings p.a. per ft. run
Hence, capital cost per ft run .... = 156 shillings

For mains in bank
Fixed charges at 12 per cent .... = 15·8 shillings p.a. per ft run
Hence, capital cost per ft run .... = 132 shillings

Assuming the weighted cost of money at 7 per cent per annum, the value of capital sunk now becomes in five years' time :—

Case " Separate " .... $156\,(1{\cdot}07)^5 = 219$ shillings per ft.
Case " Bank " .... $132\,(1{\cdot}07)^5 = 185$ shillings per ft.

an advantage for Case " Bank " over Case " Separate " of 34s. per ft run, or 15·5 per cent.

If it is decided to construct now instead of in five years' time, the possibility of combining these two culverts with, say, two required for present needs, to form a bank of four, instead of two banks of two, must be considered, when, from Fig. 34 a further saving of approximately 6·25 per cent could be achieved (for Case "Bank ").

Among other advantages to be listed for the bank construction is the fact that increased width is obtained for distributing heavy live loads such as pertain to power sites, to the subsoil, and where piles are used there is the actual saving in piles, due to reduction in weight, and the savings accruing from concentrating pile-driving operations in one area, as opposed to operating in two or three different localities. Moreover, access problems are reduced, since temporary bridging of trenches is limited to one area.

The foregoing was based on the arbitrary assumption of square culverts. Actually, consideration has to be given to the question of shape, and square and circular culverts, say, have to be compared. Williamson (29) has shown, from a large number of observations covering large conduits that within close limits the friction head for conduits may be represented by the relation :

$$S = \frac{V^2\, n^2}{2{\cdot}2\, R^{1{\cdot}333}} \text{ in ft sec units}$$

where S = Loss of head per unit length.
R = Hydraulic mean radius.
V = Velocity.
n = A constant similar to " Kutter's Coefficient "—depending on the material.

For the same velocity and material, then, the friction, and hence operating cost (in siphon system) would vary according to the expression : $\frac{1}{R^{1{\cdot}333}}$.

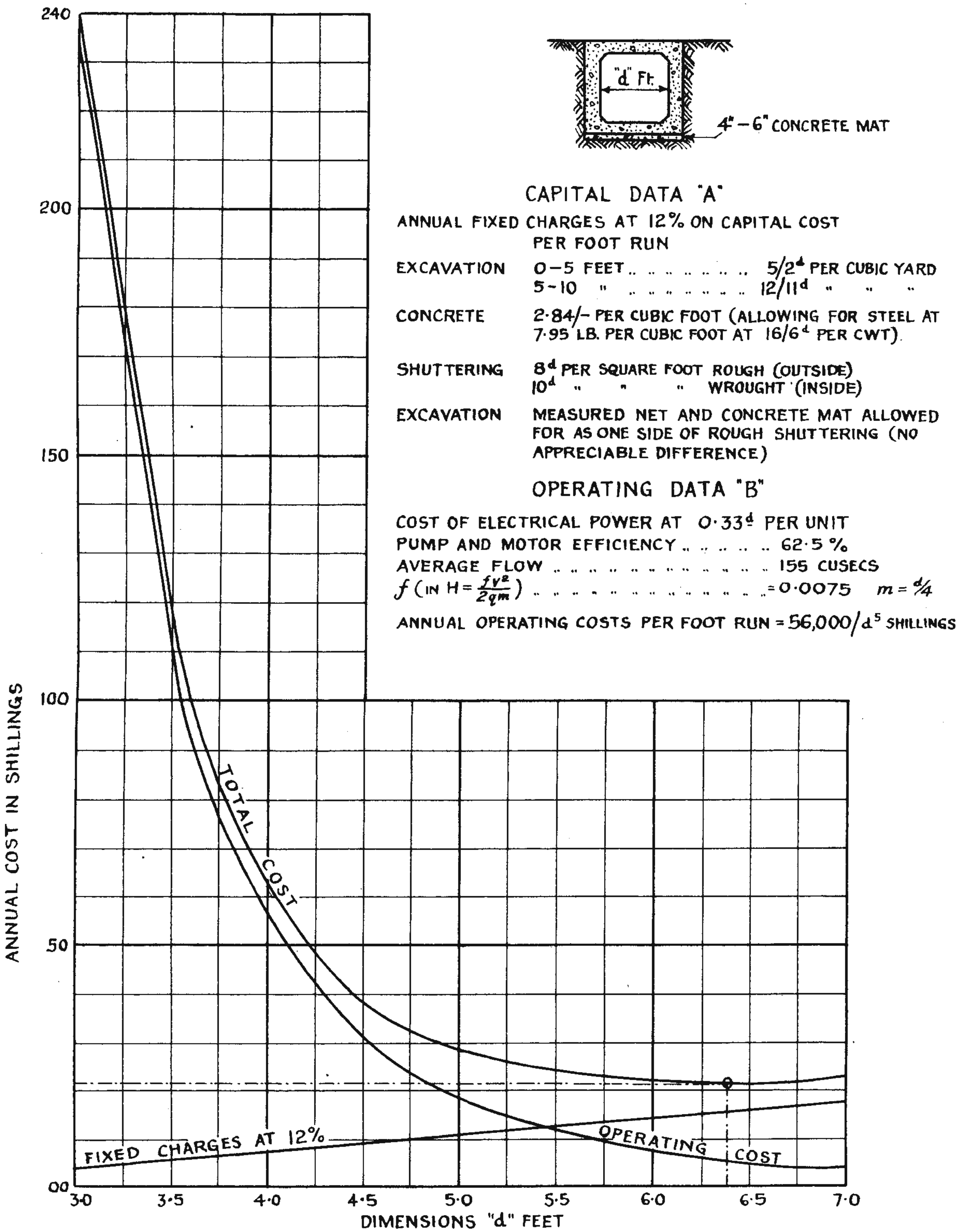


FIG. 32

GRAPHICAL ILLUSTRATION OF DETERMINATION OF ECONOMIC CULVERT SIZES FOR SQUARE R.C. COOLING WATER MAINS

SINGLE MAINS

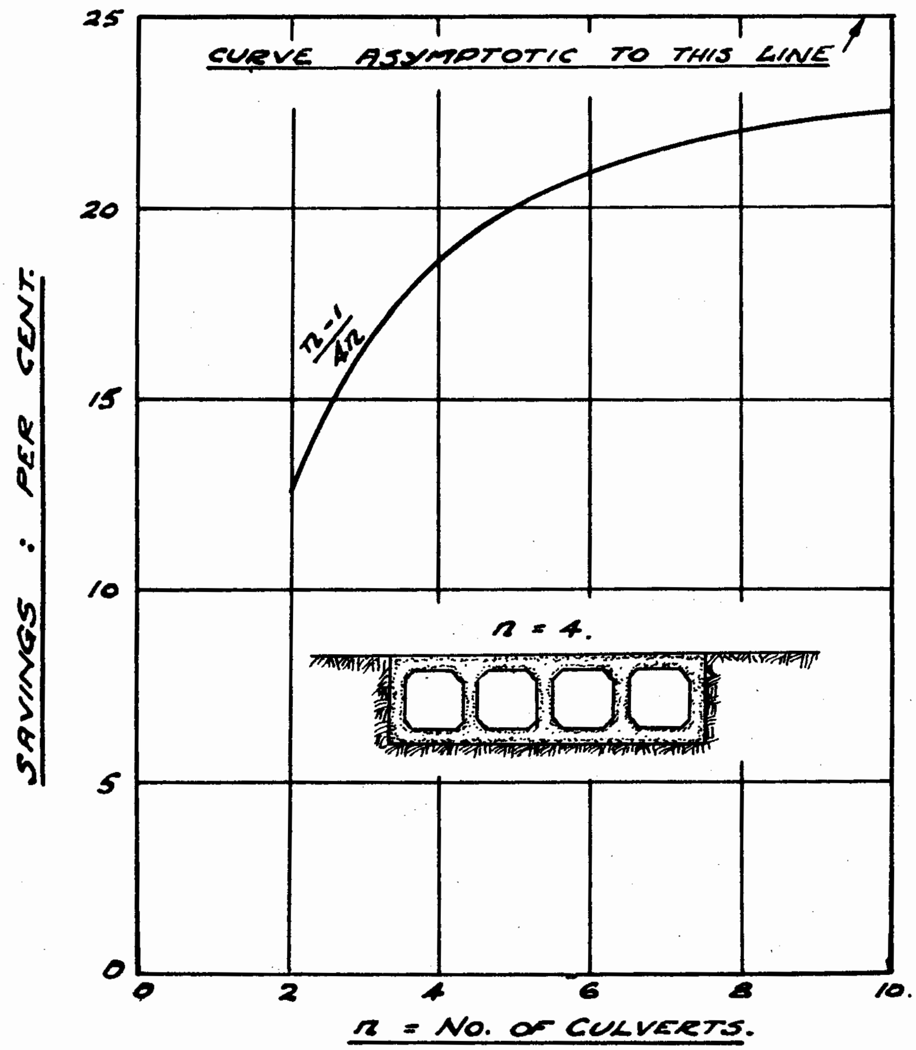


FIG. 34

PERCENTAGE SAVING IN CAPITAL COST FOR CULVERTS CONSTRUCTED "IN BANK" AS OPPOSED TO SEPARATE UNITS

Consider Fig. 35. Neglecting thickness of material, Case " A " represents a square culvert which passes the same quantity of water as a circular culvert shown in Case " B." Then d, the diameter of the circular culvert $= 1 \cdot 13$ D (where D is the water width for the square culvert).

Hence O_s/O_c = (Ratio of Operating Costs " Square " to Operating Costs " Circular ")

$$= \left(\frac{1}{0 \cdot 885}\right)^{1 \cdot 333}$$

$$= 1 \cdot 18$$

or operating cost square exceeds operating cost circular by 18 per cent. From Figs. 32 and 33 it is evident from the shape of the operating cost curves that these effects would be more pronounced for small diameters than for the larger ones—a fact to be borne in mind.

Excavation (Measured Net)

Excavation, square .... D^2

Excavation, circular .... $= d^2 = 1 \cdot 27D^2$

Excess : Circular—Square .... 27 per cent

But the story does not end there. Excavation may be specified net, but the contractor in making up rates for tender takes into consideration the disposal and/or backfilling of material. There is therefore a definite factor of backfill cost. From Fig. 35 :—

Backfill, square .... = Zero

Backfill, circular .... $= 1 \cdot 27D^2 - D^2$
$= 0 \cdot 27D^2$

Or, for circular culverts there is a constant ratio :

Backfill/Excavation of $\frac{0 \cdot 27D^2}{1 \cdot 27D^2}$......... $= 0 \cdot 21$.

Generally speaking, this backfill placed round culverts has to be carefully placed and compacted (see later under external loading considerations), thus introducing further cost increase.

Shuttering

A smooth inside surface is necessary, not only from the point of view of friction and operating cost, but also from the point of view of deterioration and the start of growths. Hence wrought or steel shuttering is usually employed for inside faces, whatever is used for outside shuttering.

Wrought shuttering, square .... = 4 D

Wrought shuttering, circular .... = 3·55 D

Rough outside shuttering, square .... = 3 D

Rough outside shuttering, circular ...... = 3·55 D

(Allowing a third side as shuttering for square culverts to cover for a thin, weak concrete mat under the culvert.)

For square culverts, especially in banks, it is possible to use as outside shuttering sheeting timbers retaining trench walls, which generally means leaving it in permanently. In this case the cost of timber has to be balanced against the savings of excavation and of timber removal costs. This procedure is obviously impossible in the case of circular culverts.

Materials

Circular conduits will, on the whole, have the advantage over square culverts as regards materials of construction. A rational comparison is not possible along the lines above, as much of the data is tied up with considerations such as external loadings adopted, and questions of durability, permeability, storage space, etc. Fully designed cases have to be compared, bearing in mind the following additional factors :—

(1) For direct support on soils the square culvert needs very little bedding preparation. Thus a mat of weak concrete will usually suffice, and pile caps—where piles are used—are generally unnecessary. For circular culverts, however, bedding conditions become a major problem, especially where heavy fills and live loads have to be considered. Fig. 36 (26) illustrates four cases of bedding conditions. When supported on piles attention has to be given to special caps for circular conduits, and square culverts have the further advantage that the ease with which steel reinforcement could be disposed in an effective manner to deal with longitudinal stresses gives them a greater spanning capacity.

(2) The increased economy of constructing in " bank " as previously discussed is not obtainable for circular culverts to the same degree as for square culverts.

(3) Square culverts are more readily multi-functional than circular culverts, a factor of increasing importance in Power Engineering. Thus it is possible with square culverts, and especially when constructed in banks, to support conveyor trestles, sluice trenches, compressed air and other pipes, etc., with only minor incremental cost increases for foundations, whereas in the case of circular conduits special attention has to be given to the design of special supports or hangers and to existing bedding conditions.

(4) Inspection is facilitated in the case of square culverts. In the case of circular culverts, unless special inverts are cast, it is somewhat difficult to walk along a slippery culvert.

(5) A disadvantage of square culverts is the necessity for transitions to be constructed where it is desired to change from square to circular, and vice versa, at junctions with bus pipes, which are usually kept circular for the purpose of including standard isolating valves. Both capital and operating costs go up with transitions.

(6) An advantage often quoted for circular conduits is the ease of prefabrication and hence better curing conditions, re-use of shuttering, etc., but against this must be offset the site storage space required, transport and handling difficulties arising from aligning and jointing, and number of joints to waterproof.

The decision as to shape will, therefore, only be taken after weighing up all the factors influencing capital and operating cost, time factors, multiple use, etc., and possibility of obsolescence.

Research work is necessary to establish whether the coefficient of friction does in fact vary with shape of culvert, i.e. whether " f " differs much for square culverts from that of circular culverts. At first sight it would appear as if there might be a " drag " to flow in the corners of a square culvert, and hence that f measured for a square culvert may be larger than that measured for a circular culvert.

So far concrete has been considered as the permanent material of construction. Cast iron and steel pipes have been used in a number of cases and some notes on thes materials are essential in order to complete the picture.

S. H. W. Middleton (30) defines the ideal for a conduit as follows :—

" The water mains must be watertight under all normal working conditions, and must be of sufficient strength to withstand not only the working pressure, but also the shocks

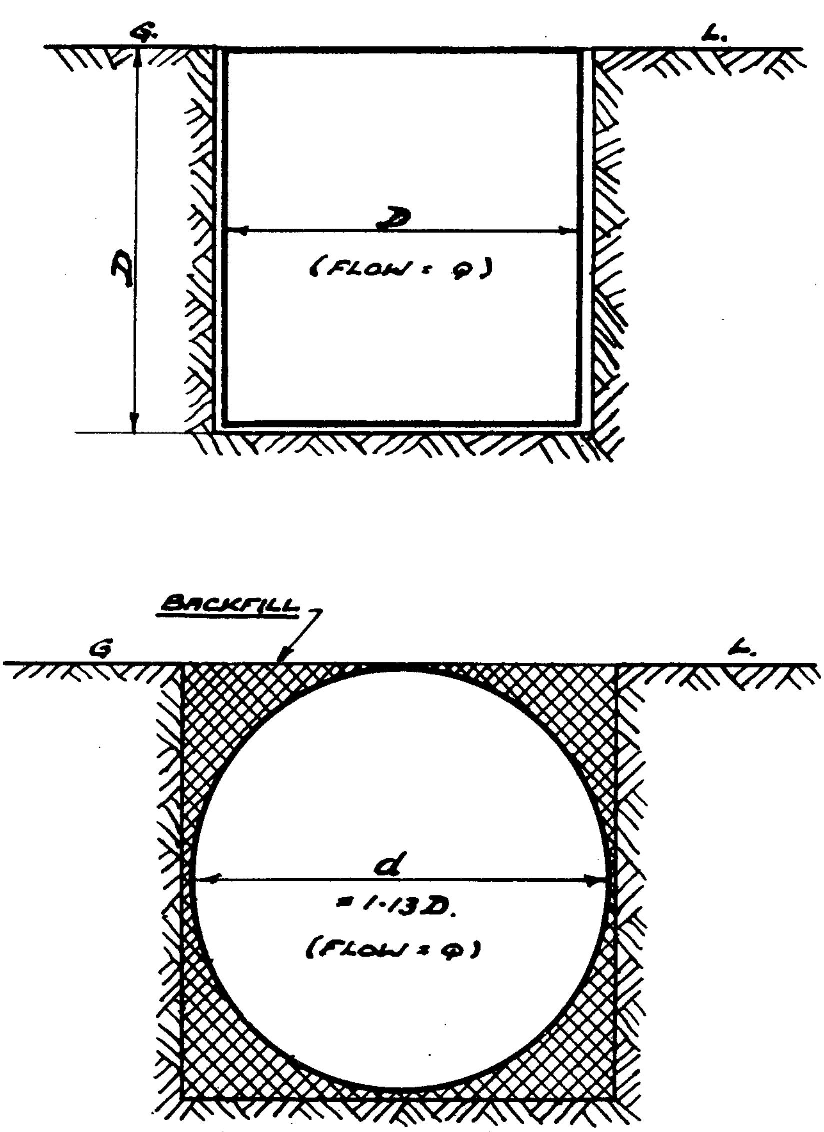


FIG. 35

DIAGRAM COMPARING SQUARE AND CIRCULAR CULVERTS

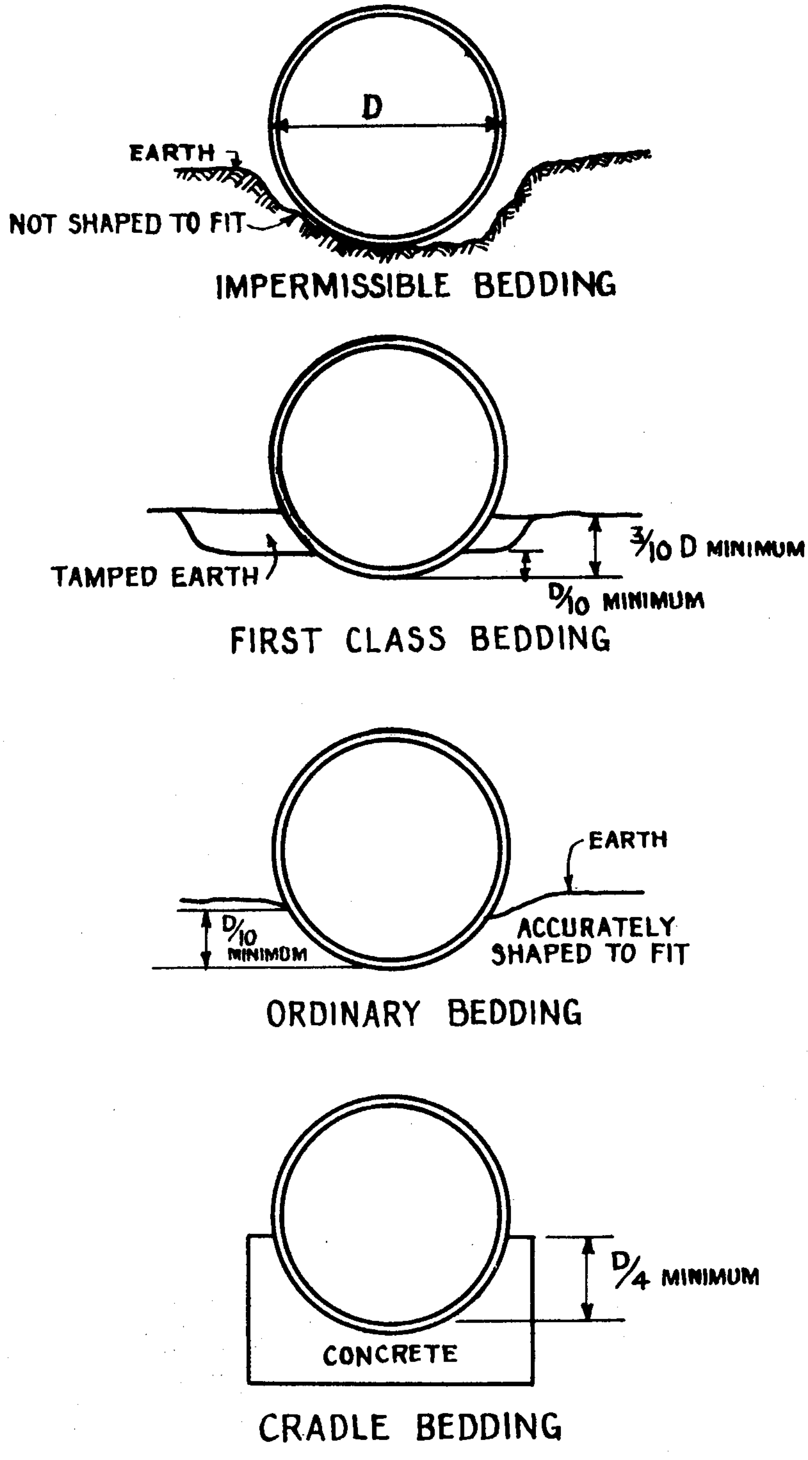


FIG. 36

BEDDING CONDITIONS — CIRCULAR CULVERTS

FROM.........(26)

to which the mains are subjected by the sudden closing of valves and the movement within the main when charging ; it must be capable of resisting earth pressure, and accommodate itself to disturbance of the ground due to heavy traffic passing over it ; it must provide free and easy path with least possible friction for the water flowing through it, and it must lend itself to the formation of efficient watertight joints."

Cast Iron Pipes

Mr. Middleton suggests that the cast iron pipe fulfilling these conditions must be wasteful of material because the thickness required must be so great as to constitute a very heavy pipe. The question of corrosion which may reduce the carrying capacity materially may entail the design of a pipe having a bore considerably in excess of the required capacity. A lighter pipe of denser material has, however, been produced by the centrifugal process. . . . It is further claimed that these pipes are subject to less friction loss owing to greater smoothness of inner surfaces, and that they are less liable to corrosion. . . . One drawback is that it is impossible to make spun cast iron specials, but sand cast specials could be used. These pipes are made in lengths up to 18 ft.

Steel Pipes

" . . . Where pressures in excess of 100 lb per sq. in. have to be encountered the thickness of metal required in cast iron pipes of large diameter becomes so great that the advantages of steel become apparent. . . . Fifty years' service is mentioned to illustrate length of service for steel pipes, whilst for cast iron pipes reference is made to the pipes installed in Versailles in the 17th century and which are still in service. . . .

" . . . Owing to insufficiency of coating protection it was previously necessary for the engineer to provide thickness of metal for deterioration. Since that time attention has been given to many methods of protecting steel. . . . Various systems of lining tubes with concrete have been tried, the most successful being those where the concrete was applied centrifugally, giving a high value for adhesion between steel and concrete. The protection afforded appears to be satisfactory and the original discharge capacity of such pipes has been well maintained. External protection has been afforded, generally by surrounding the pipes with concrete or by lapping with hessian soaked in bitumen. . . . In all internally lined pipes the lining is apt to be broken at the joints, particularly in the case of the concrete lining, unless the pipes are large enough for a plasterer to get in and plaster the joints by hand. . . . The most telling advantage seems to lie in the fact that so far as the author was aware there was no instance recorded of a steel main having burst."

Sundry comparative data is given below :—

Description	*Cast Iron*	*Steel*
Tensile strength : tons/sq. in.	6–17	28–33
Mod. of elasticity : lb/sq. in.	$14{\cdot}1$–$21{\cdot}2 \times 10^6$	30×10^6
Specific gravity..................	6·9–7·5	7·8
Lengths manufactured	To 18 ft	To 25 ft

The tremendous progress made in the sphere of welding, which has overcome to a large extent sundry problems concerned with watertight jointing and construction problems in out of the way sites where access and transport facilities are at a premium, has boosted steel as opposed to cast iron, since progress as regards welding the latter has not advanced equally far.

The lining of circular bus pipes of large size *in situ* is usually carried out by the use of the concrete gun. Speed of work is usually limited by the number of plasterers that can be deployed behind the concrete gun, to render the surfaces smooth before initial set has occurred.

A difficulty that has to be overcome is the formation of " dead " or " hollow " pockets of sand behind reinforcing bars, especially at points where bars cross. By suitably grading the mixture and by control of the water/cement ratio, and by finding, experimentally, the best angle of shooting, this difficulty can be overcome, and the author has been associated with work where watertight work has been achieved with gunite thicknesses of 2 to $2\frac{1}{2}$ in under 40 ft of water head. The best results were obtained by concentrating first on the under-reinforcement areas and just covering the steel, and then by using a smaller gun, to put on a finishing layer of about $\frac{3}{8}$ in to $\frac{1}{2}$ in thick, taking care to stagger all joints. The surface of the first layer has to be rough but clean. Plastering was much reduced by this method, as the handling of a $\frac{1}{2}$-in layer of wet material is a very different problem from that of handling a wet layer $2\frac{1}{2}$ in thick. It is also possible to make the final layer of richer mix or of aluminous cement. But in the latter case more supervision is necessary to ensure that " crazing " does not result.

Research and experience having shown that it is possible to specify a mixture of concrete which, with good workmanship and proper curing, would give an impermeable concrete with hard-wearing qualities and very high strength, engineers are more and more inclined to the use of this material for power conduits, where working heads are unlikely to exceed 100 ft. Apart from all the previously indicated advantages, e.g. multiple use factor, bank construction, etc., there is the greater choice as regards shape, size and construction methods to be considered.

Photograph 1 shows the external shuttering complete and set up to receive reinforcement for the square reinforced concrete cooling water mains of Littlebrook " A " Power Station.

Photograph 2 illustrates the reinforcement going into place for concreting. For typical details see Fig. 37.

Photograph 3 shows the culverts concreted. In the right foreground is shown the copper expansion joint in place, and the expansion shrinkage space which is concreted at a later date.

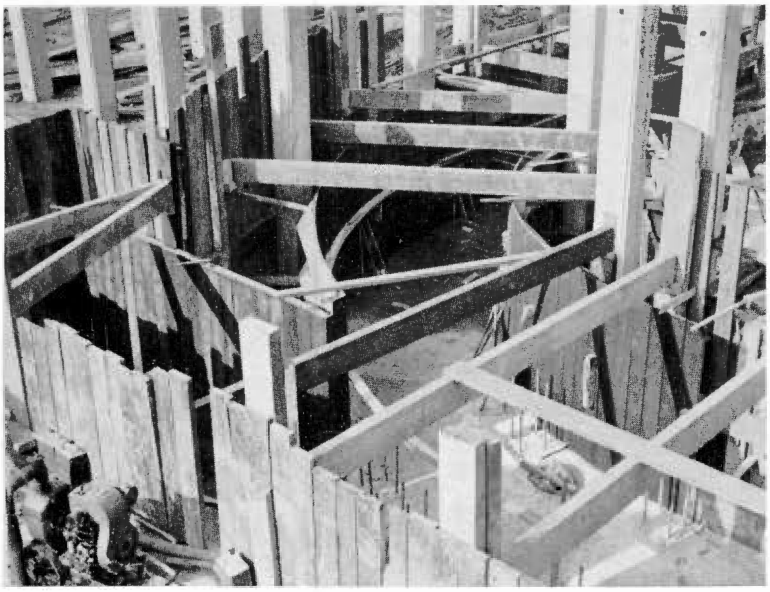
The above three photographs were all taken from the same point, and they show the junction of two culverts to become a twin main, or " Case Bank."

With sea water it must be remembered that the minimum cover necessary to avoid penetration of sea water to the reinforcement with consequent rusting and welling of the latter, and spalling and deterioration of concrete, is about 2 in, even for a comparatively rich mixture (33).

Fig. 37 shows typical square concrete culverts as constructed for Littlebrook Power Station.

The question of permissible velocities has been referred to by Davis (38) thus :—

" . . . for clean water in smooth concrete or other hard surfaced channels, the limiting velocity is beyond practical requirements . . . velocities above 40 f.p.s. for clear water in concrete channels have been found to do no harm. If the water carries abrasive material damage may occur with much lower velocities. Unless the abrasive material is particularly bad, velocities of 10 to 12 f.p.s. should not prove injurious to first-class concrete."



Photograph No. 1

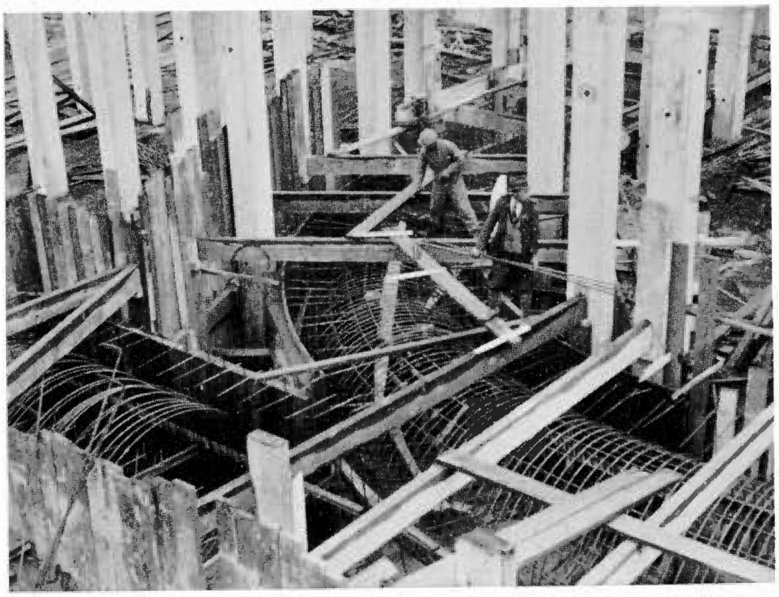
Cooling water culverts at Littlebrook Power Station, showing external shuttering in place ready to receive reinforcing steel. Note the projecting steel from the reinforced concrete piles.

(By courtesy of Sir Alexander Gibb & Partners.)

Photograph No. 2

Cooling water culverts at Littlebrook Power Station showing reinforcement being placed prior to placing internal shuttering and concreting. See also Photograph No. 1 *and Fig.* 37.

(By courtesy of Sir Alexander Gibb & Partners.)



Williamson's figure (29) quoted for permissible velocities in crown bends of siphons varies from 15 to 32 f.p.s.

For power work velocities seldom exceed 10 f.p.s., but the question of abrasive silt has to be given attention and periodic inspection is necessary to make sure that mechanical deterioration of surfaces has not occurred. Further research is also necessary to investigate whether cavitation is present in culverts under negative pressure, and what deterioration results as a consequence.

The extensive use during war time of welding has shown that considerable savings are possible by the use of this method in connection with culvert construction. It is possible to prefabricate reinforcement in accurate cages which can be held firmly in place during concreting, and serves to hold shuttering in place if suitably designed. There is actually a saving in material due to avoiding of laps.

Thus for the circulating water tunnels of the " Harbor Steam Plant for the Department of Water and Power of the City of Los Angeles, California," steel pipes were first considered. But, because of war conditions, it was abandoned in favour of steel reinforced concrete pipes. Tests have shown the reinforced concrete pipe to be 10 per cent cheaper than the steel pipes, and it had the additional advantage of much quicker delivery and probably longer life in sea water, besides the saving of essential war materials (31). Here the reinforcement was wound on to mandrels and welded to horizontal rods and spacers. Each weld had to test to a strength of 40,000 lb per sq. in. Altogether 4,976 lineal feet of pipe, inside diameter 96 in, outside diameter 106 in, was made and laid at a total cost of 211,480 dollars. The reinforcing steel, amounting to 491 tons, cost 30,636 dollars (steel : 17·9 lb per cu. ft. concrete).

The following conclusions, after a series of experiments recorded by R. H. Evans (32), have some bearing on this work :—

" Summarising, the test results show that overlapped tensile rods, with hooked ends and with all rods overlapping over the same portions of the beam do not form a reliable and efficient means of jointing the reinforcement. The reinforcement, if this method is to be used, should be generously staggered so that a large proportion of the tension reinforcement rods is continuous near the overlapped joint of each rod. The use of deformed bars, though allowing a higher load stress, would not change the cracking loads, with the result that the tendency to produce vertical tensile stress in the concrete would be inherent still in the method of jointing. There is no doubt that, if joints are necessary in the tensile reinforcement, the most efficient and dependable results are obtained by welding."

This is agreed provided the specification ensures an adequate standard of welding.

The values suggested by Williamson (29) for " n," the roughness or friction constant, for use in his friction formula shown in Table 12, give an idea of the relative carrying capacities of the different materials.

The question of external loading on conduits due to fill, live loads, etc., has been the subject of intensive research in America, but although certain principles have been enunciated, much work remains to be done, and the engineer must be largely guided by experience in the matter of loadings allowed for.

A. Marston, who has been conducting research at the Iowa State College since 1909 has formulated a theory of external loads on closed conduits (34), whereby the loads supported are derived by the use of one of two formulæ, according to the fill conditions.

TABLE 12

VALUES OF COEFFICIENT OF ROUGHNESS "n" FOR USE IN FORMULA

$$S = \frac{V^2 n^2}{2{\cdot}2 R^{1{\cdot}333}} \quad (29)$$

Material	*Value of "n"*
Rough concrete	0·0170
Ordinary concrete from rough forms	0·0130 to 0·0145
Dressed masonry Smooth, flush-pointed brickwork Very well finished concrete	0·0125 to 0·0130
Concrete lined tunnel, and reinforced concrete conduits from new steel frames	0·0115 to 0·0125
New cast iron pipes, smooth coating Welded steel pipes, smooth coating	0·0110 to 0·0125
Smooth plaster of cement and sand	0·0115 to 0·0120
Large machine-made concrete pipes, clean	0·0100 to 0·0115
Lapped, riveted pipes, smooth coating	0·0130 to 0·0145

Case 1. $W_t = C_t w B^2$ = vertical external load on pipe in lbs per ft run.

Where C_t = experimental coefficient derived from Fig. 38.

w = unit weight of fill material : lb per cu. ft.

B = width of trench at top of pipe : ft.

and applies to pipe completely buried in trench where *B does not exceed* 1·5 *D*, as shown in Fig. 39. The theory is that, as the fill settles it sets up arching, and sliding stresses on the trench walls, the pipe being thus relieved of super loads.

Case 2. For pipes laid in the original ground surface, pipes projecting above shallow trenches, or pipes laid in trenches where B exceeds 3 D, the equation is :—

$$W_p = C_p w D^2 \qquad \text{(Fig. 39b)}$$

Where C_p is the experimental coefficient found from Fig. 40.

But the difficulty in applying these formulæ lies in the following :—

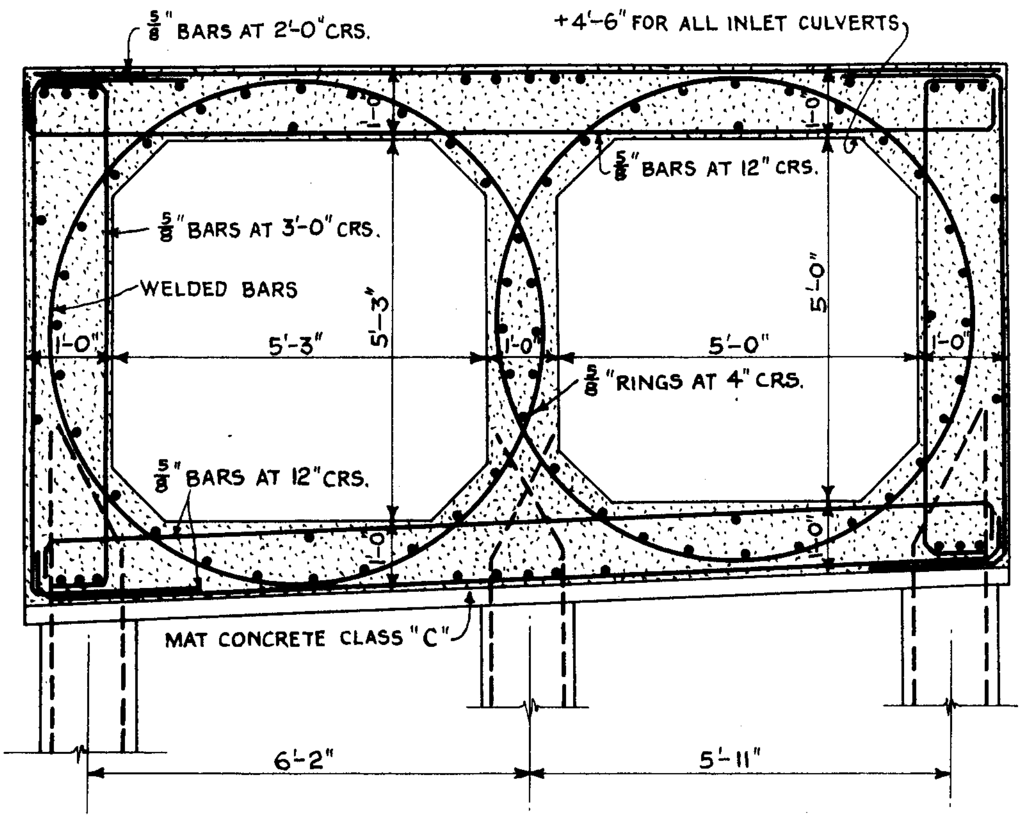
(i) Fig. 40, giving experimental coefficients apply *only* to non-cohesive materials. Interpolation, requiring extensive experience, is necessary in the use of Figs. 38 and 40.

(ii) The intermediate case, where B is greater than 1·5 D but less than 3 D, would not seem to be covered and requires further " interpolation."

(iii) The author is extremely doubtful of even experienced engineers being able to assess the degree of projection for use with Fig. 40.

(iv) The theory assumes fully rigid pipes.

Fig. 42 gives the results of a full-scale earth experiment carried out in America on culvert pipes, with 100 per cent projection, sand fill (35). The loading suggested would seem to be in the region of 1·4 to 1·5 of the actual weight of fill directly over the pipe. From the deflections observed, the passive resistance of the earth may have come into play in relieving pressure, that is, the pipe may be considered as partially " flexible."



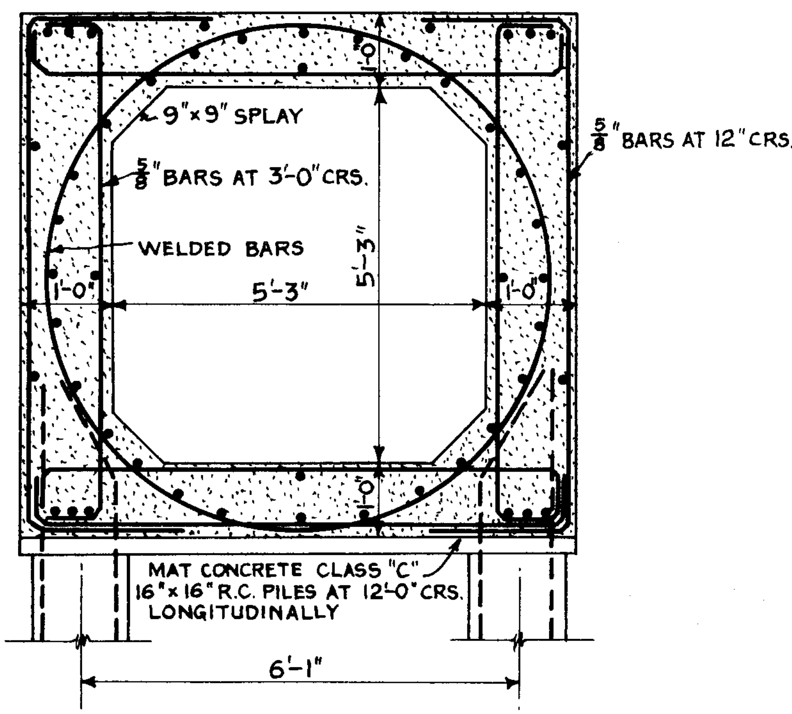


FIG. 37

A TYPICAL EXAMPLE OF THE ARRANGEMENT AND REINFORCEMENT OF SQUARE R.C. CULVERTS, SINGLE AND DOUBLE MAINS (IN BANK).

LITTLEBROOK POWER STATION
KENT ELECTRIC POWER Co.
(BY COURTESY OF SIR ALEXANDER GIBB & PARTNERS).

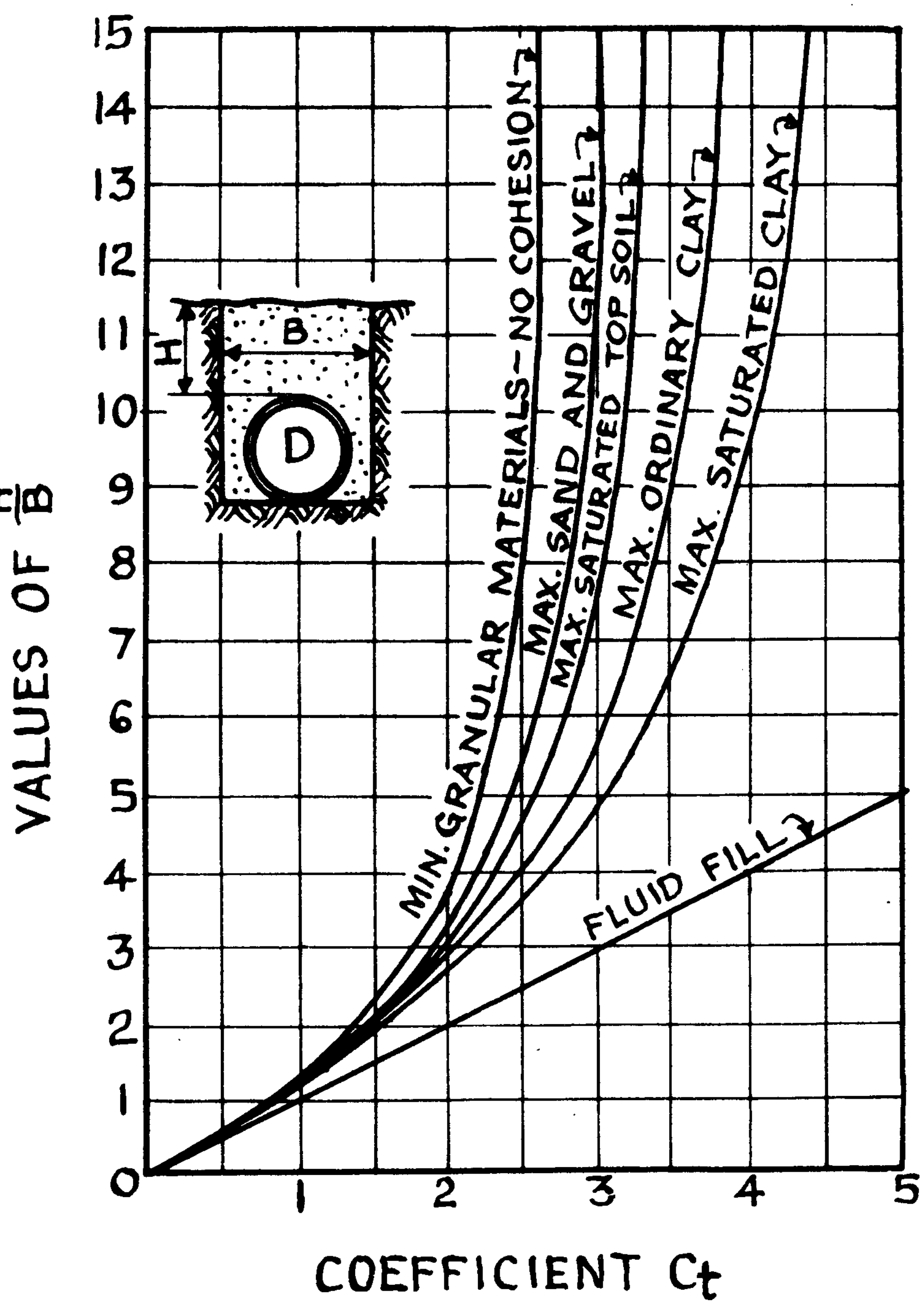


FIG. 38

VALUES OF COEFFICIENT Ct IN EARTH PRESSURE EQUATION $w_t = C_t\, w\, B^2$ FOR TRENCH CONDITIONS, ALL MATERIALS, AND B NOT GREATER THAN 1·5 D.

FROM .... (34)

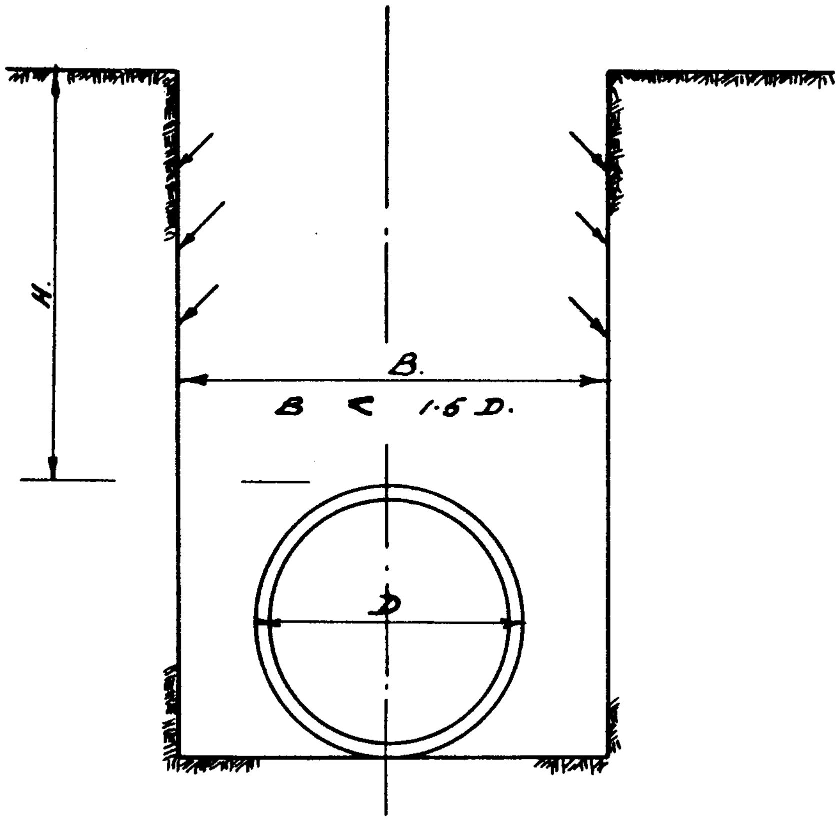


FIG. 39A

CONDITIONS FOR MARSTON'S FORMULA: $W_t = C_t . w . B^2$

FOR VALUES OF C_t, SEE FIG. 38

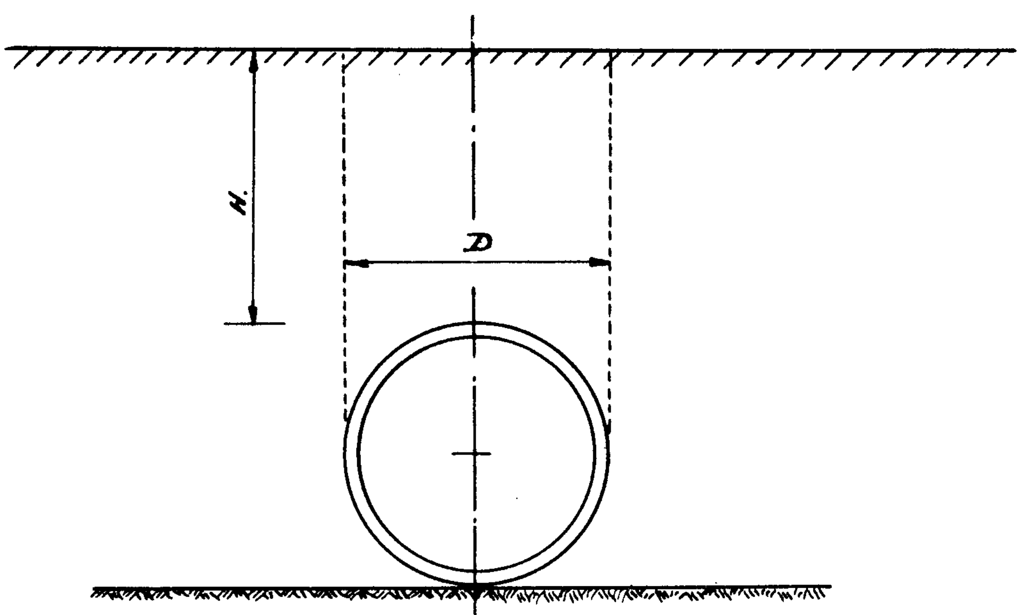


FIG. 39B

CONDITIONS FOR MARSTON'S FORMULA: $W_p = C_p . w . D^2$

FOR VALUES OF C_p SEE FIG. 40

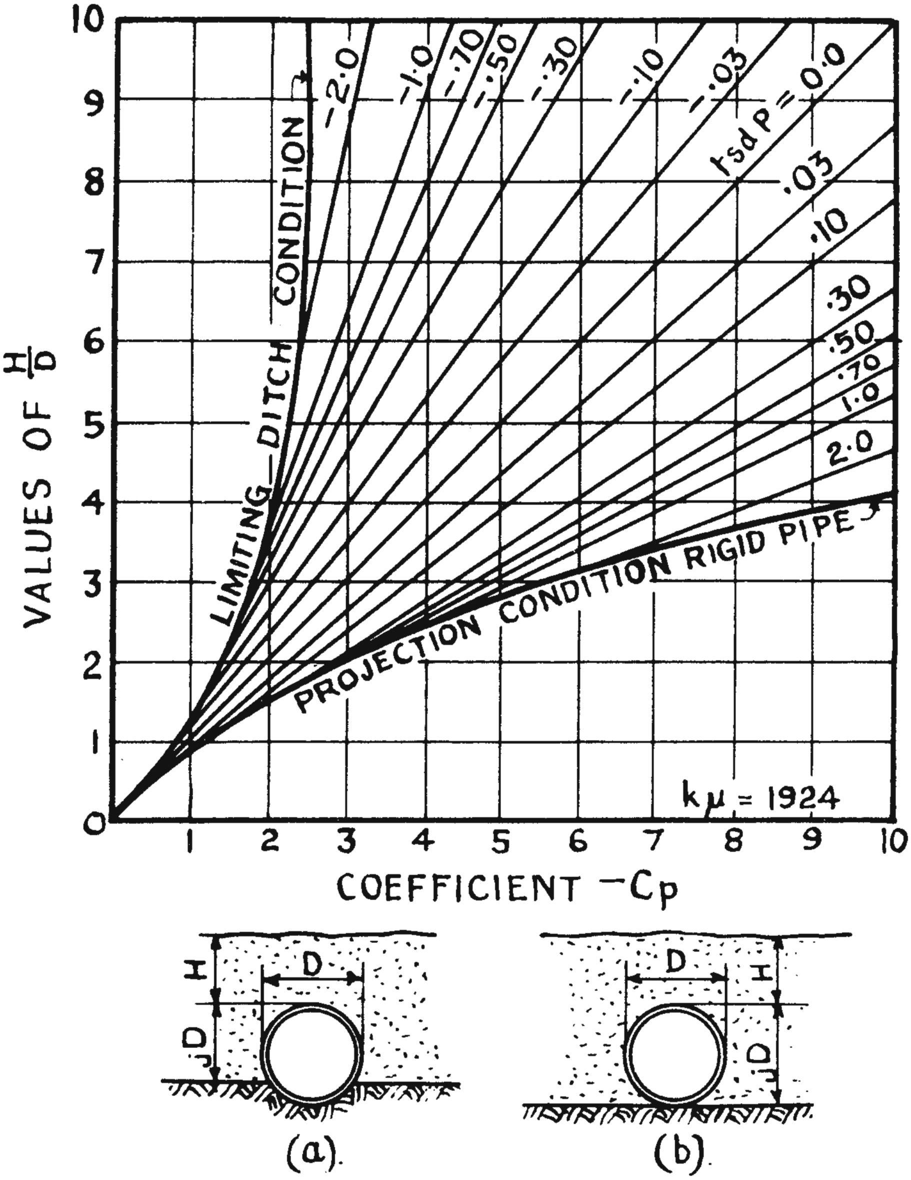


FIG. 40

VALUES OF COEFFICIENT C_p IN EARTH PRESSURE EQUATION $w_p = C_p w D^2$ FOR PROJECTING PIPES IN NON-COHESIVE MATERIALS

FROM ....(34).

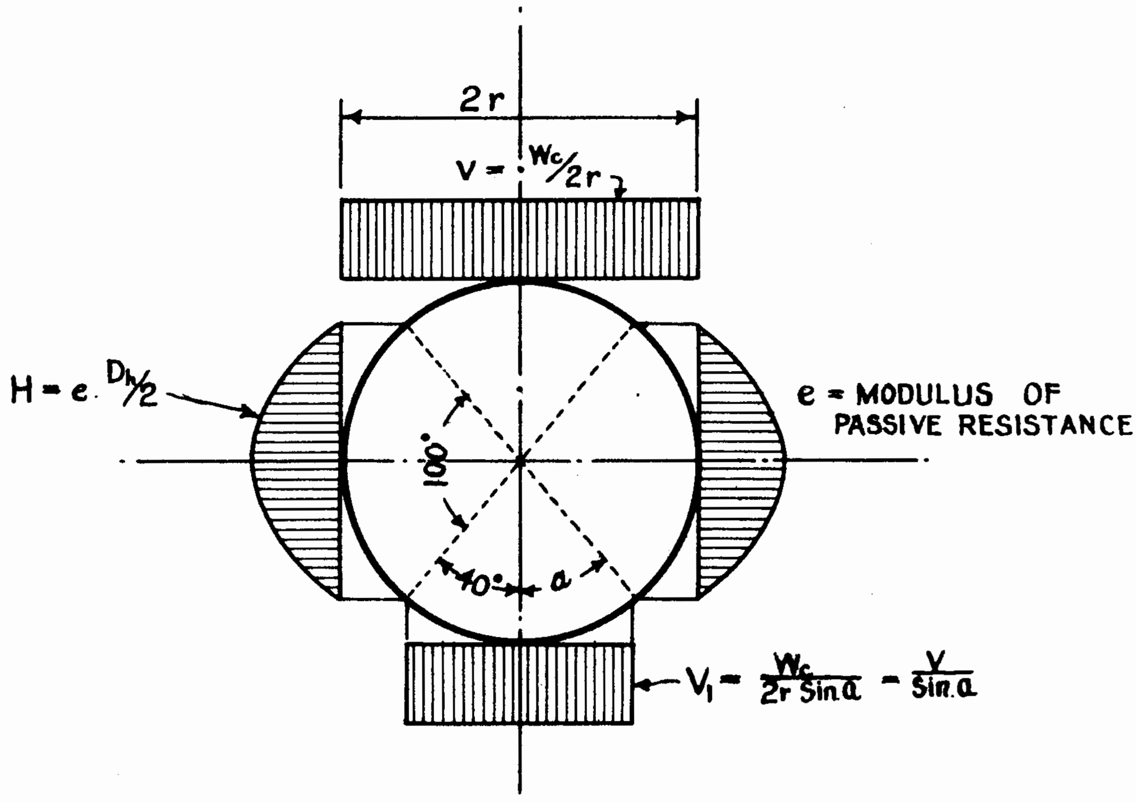


FIG. 41

DISTRIBUTION OF PRESSURE ROUND A FLEXIBLE PIPE UNDER EARTH FILL

FROM......... (36)

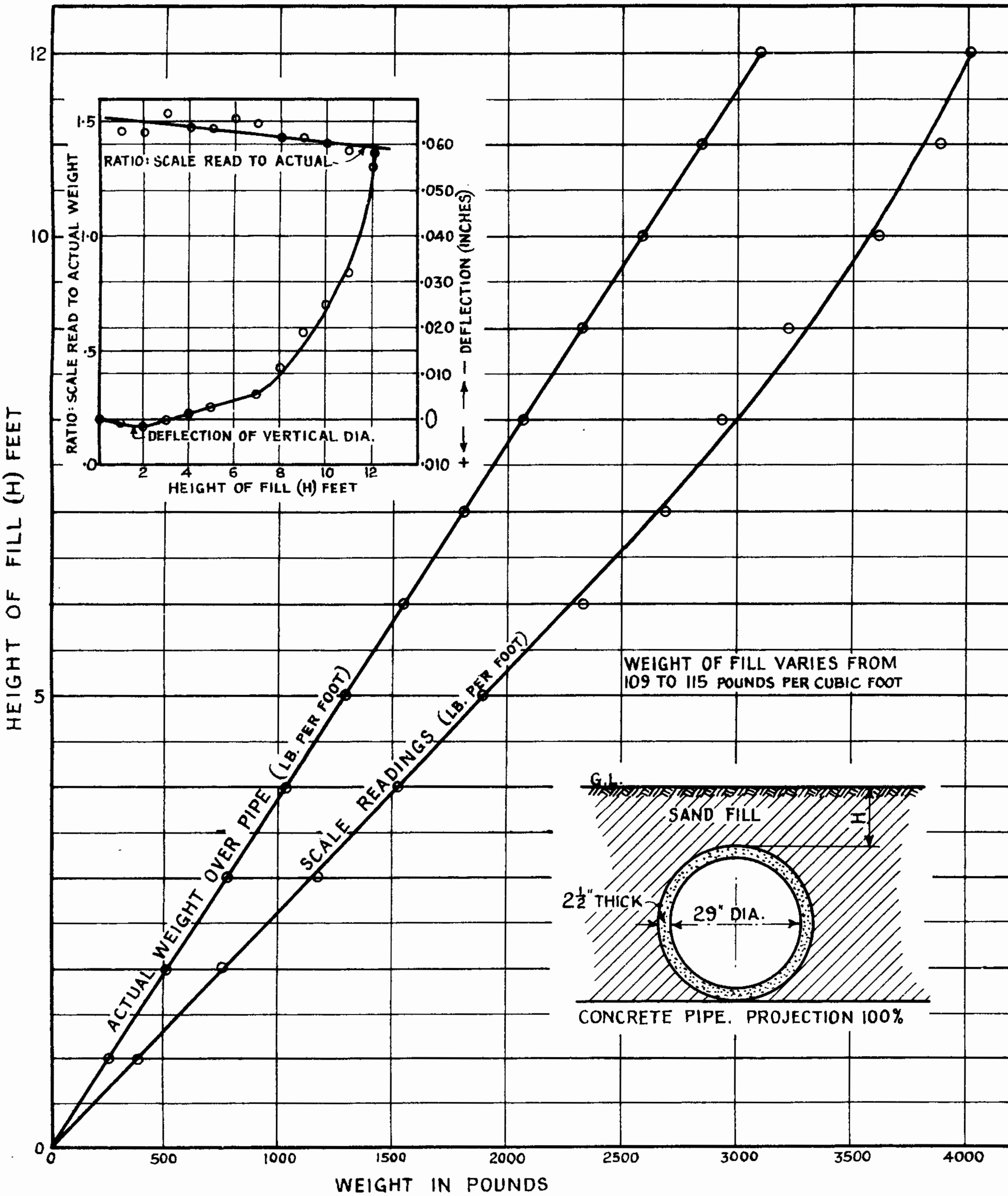


FIG. 42

EARTH PRESSURE EXPERIMENT CARRIED OUT ON CULVERT PIPE IN NORTH CAROLINA UNIVERSITY IN CO-OPERATION WITH NORTH CAROLINA HIGHWAY COMMISSION AND THE U. S. BUREAU OF PUBLIC WORKS

FROM.......(35).

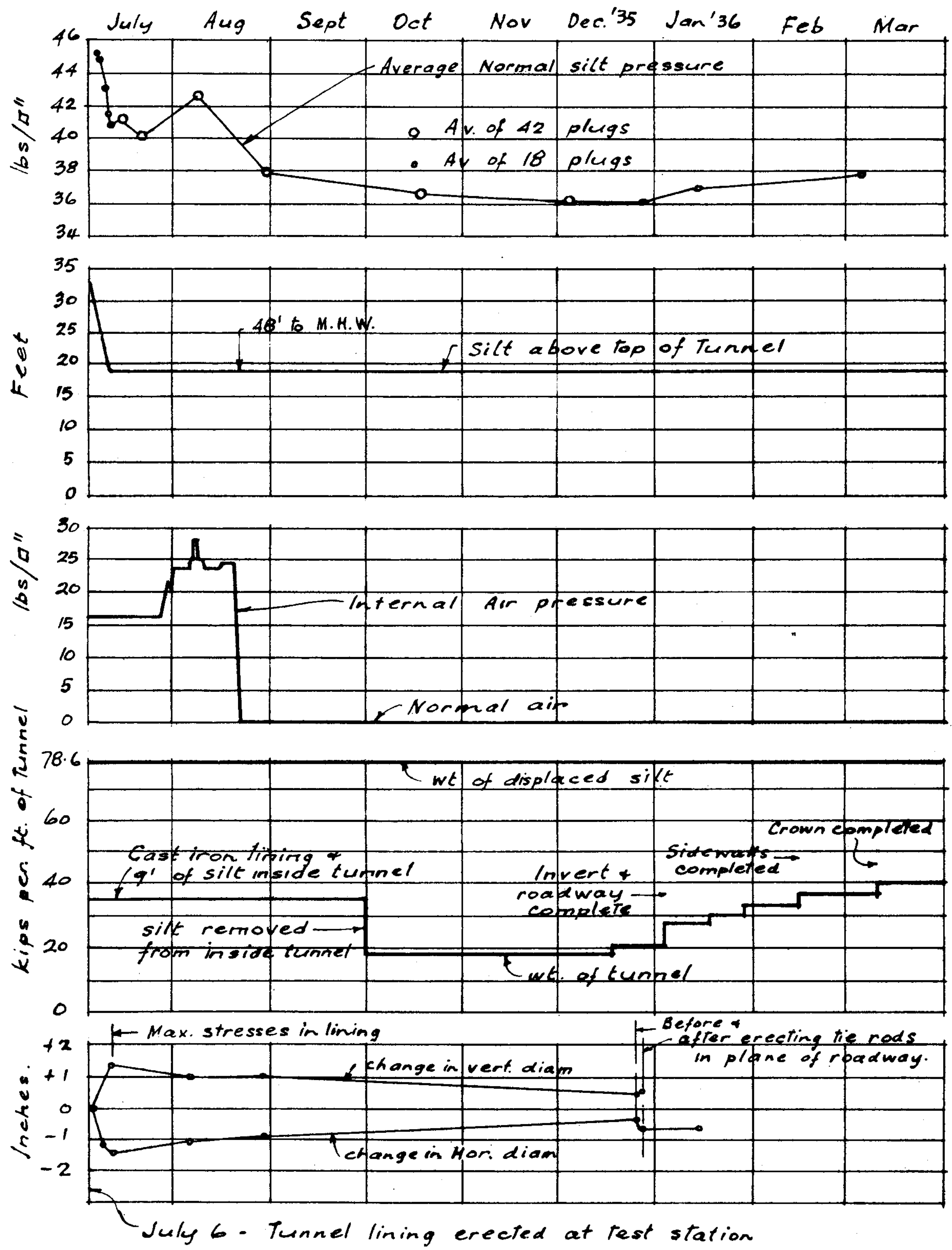


FIG. 43

LOG OF AVERAGE NORMAL PRESSURES AND INFLUENCING FACTORS MEASURED ON THE LINING OF THE MIDTOWN-HUDSON TUNNEL, NEW YORK.

(SEE ALSO FIG. 44)

FROM......(37)

NOTE:

Miscellaneous additional tests were devised to investigate the following physical properties of the silt:- shear, tenacity, elasticity, + permeability. Shearing resistance which was measured under variable pressure was found to be as follows:-

(1) The ult. (yield point) shearing resistance of Hudson R. silt in terms of the normal pressure:-

$$r = \frac{1{\cdot}34\, p_n + 7{\cdot}20}{40}$$

(2) The ult. cohesion:-

$c = 0{\cdot}18$ lbs/□"

(3) The cœfficient of friction:-

$f = 0{\cdot}0335$

(4) The angle of internal friction

$\phi = 1^\circ.\ 55'$

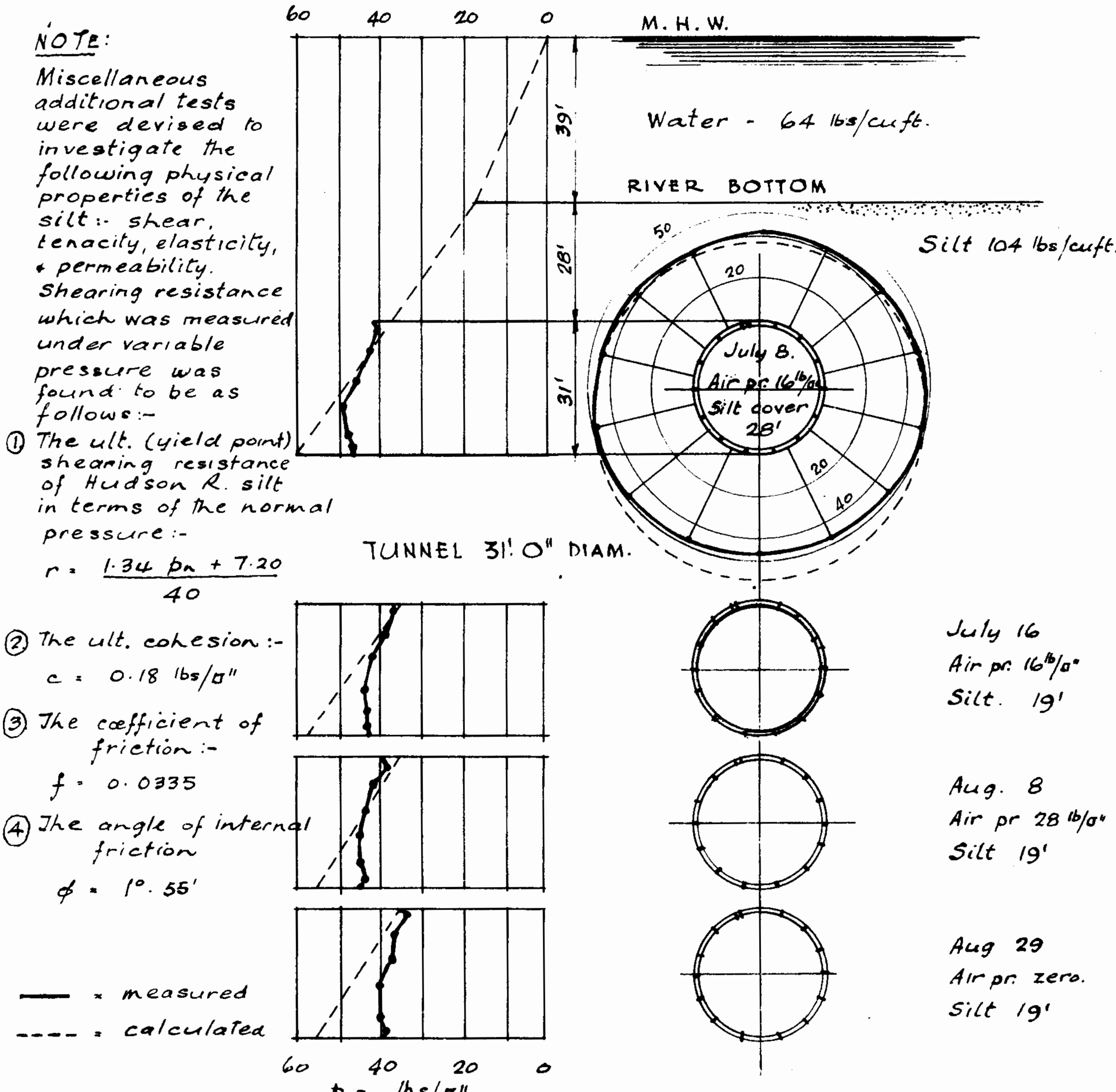


FIG. 44

THE MEASUREMENT OF SOIL PRESSURES AND THE DISTRIBUTION OF NORMAL PRESSURES ON THE MIDTOWN-HUDSON TUNNEL, NEW YORK.

(SEE ALSO FIG. 43)

FROM......(37)

Some very interesting experiments on flexible culverts are reported by M. A. Spangler (36), and the following are some of his conclusions :—

(1) The vertical load on a pipe may be determined by Marston's theory of loads on conduits and is distributed approximately uniformly over the breadth of the pipe.

(2) The vertical reaction on the bottom of the pipe is equal to the vertical load and is distributed approximately uniformly over the width of bedding of the pipe.

(3) The passive horizontal pressure on the sides of the pipe are distributed parabolically over the middle 100 degrees of the pipe and the maximum unit pressure is equal to the modulus of passive pressure of the sidefill material multiplied by one-half of the horizontal deflection of the pipe. The distribution of pressures round a flexible pipe in accordance with these conclusions are shown in Fig. 41.

(4) The ultimate horizontal deflection of a flexible pipe under a fill may be determined by the equation :—

$$D_h = L \times \frac{K\ Wc\ r^3}{EI + 0{\cdot}061\ e\ r^4} \text{ where}$$

K is a constant depending on the width of bedding of the pipe,

Wc is the load on the pipe per unit length of the pipe,

r is the mean radius of the pipe,

EI is the product of modulus of elasticity and the second moment of area of the pipe wall,

e is the modulus of passive pressure of the sidefill material,

L is the deflection lag factor, a normal range of values suggested being 1·25 to 1·50.

Suggested values for bedding constants " K " are given in Table 13.

TABLE 13

VALUES FOR BEDDING CONSTANTS " K " FOR USE IN SPANGLER'S FORMULA (36)

Bedding Angle Degrees	*Bedding Constant K*
0	0·110
15	0·108
22½	0·105
30	0·102
45	0·096
60	0·090
90	0·083

From his experiments e appeared to be a function of the properties of soil, particularly the density. In the experiments described the following values were obtained :—

(1) Black silty loam, not compacted .... 14 lb/sq. in./in

(2) Well graded gravel, not compacted .... 32 lb/sq. in./in

(3) Yellow sandy clay loam, not compacted .... 13 lb/sq. in./in

(4) Yellow sandy clay loam, tamped, dry .... 27 lb/sq. in./in

As far as the author is aware the only case of recorded measurements of pressures exerted by the surroundings material on the linings of tunnels is that by Rapp and Baker, of the Port of New York Authority for the Midtown-Hudson tunnel (37). Their observations are recorded in Figs. 43 and 44. It is very interesting to note from Fig. 43 how sensitive was the normal external pressure on the lining to the live or super loads imposed. From Fig. 44 it is of interest to note how closely the measured pressures approximated to the calculated values, and how the measured values deviated from the values suggested by calculation. In general, the calculated values were on the safe side.

In decisions affecting external loading of power culverts, the engineer will have to bear in mind the following, and as indicated above great care must be exercised in the use of theoretical or other formulæ, since practical conditions may not correspond to the assumptions on which the formulæ are based or on the laboratory conditions :—

(1) The type of fill and its degree of compaction. His main decision will be whether he can rely at all times on a given degree of compaction being maintained.

(2) The type of culvert, e.g. whether "rigid" or whether "flexible," i.e. whether, in conjunction with (1) he can count on passive earth pressure assistance. Generally, in British practice, the tendency is to make sure of conditions by making the pipe truly rigid and discounting possible assistance from possible passive pressures.

(3) Width of trench and degree of projection of pipe.

(4) The sensitivity of the pipe or pipe system to live loads, which may be very heavy indeed for power works.

(5) The additional loads that may be imposed on the outlet culverts of the siphon system, due to negative pressure waves, etc.

Practical Pressure Tests (full size) Carried out on a Cooling Water System

In order to obtain an idea of actual practical loading conditions in a culvert system due to pumping and other operating conditions, a series of pressure and pitometer readings were taken on the Littlebrook Power Station culvert system.

The layout of the culverts, measuring gauges, etc., is shown in Fig. 45.

Fig. 46 shows the distribution of velocity across the square culverts as recorded by pitometer readings. The distribution agrees fairly well with the typical results reported by Williamson (29) for large conduits.

Fig. 47 is a record of actual pressure conditions in the pipe system as recorded by the automatic recorders (see Fig. 45) for the operating conditions as logged.

For the layout of this station it was found that the quantity of cooling water flowing could be estimated with reasonable accuracy by using the relationship :—

$Q = 7{\cdot}4\ K/H$. cusecs.

Where K = Total kilowatts consumed by the pumps.

H = Total head supplied by the pumps, feet.

(The average overall motor-pump efficiency worked out at approximately 63 per cent.)

It is unmistakably clear from Fig. 47 that short term hammer blow effects are felt in the mains when pumps are cut in or out, or when condenser valves are shut. These quite considerable pressure waves are propagated along the mains, as confirmed by the two auto-

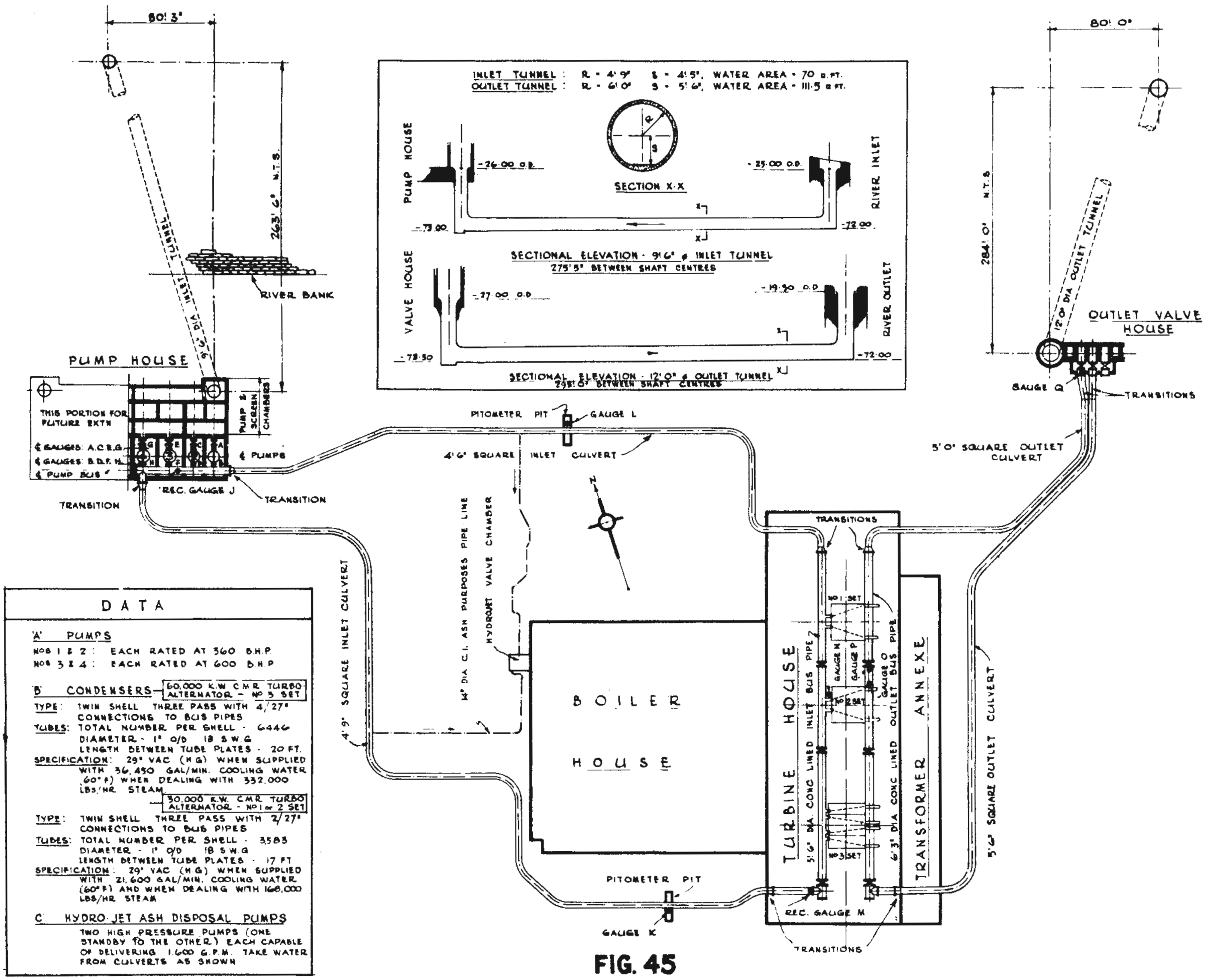


FIG. 45

KENT ELECTRIC POWER Cº
(LITTLEBROOK POWER STATION)
PLAN SHOWING LAYOUT OF COOLING WATER CIRCUITS FOR "A" STATION AND LOCATION OF TEST GAUGES INSTALLED

SCALE OF FEET

100 50 0 100 200 300

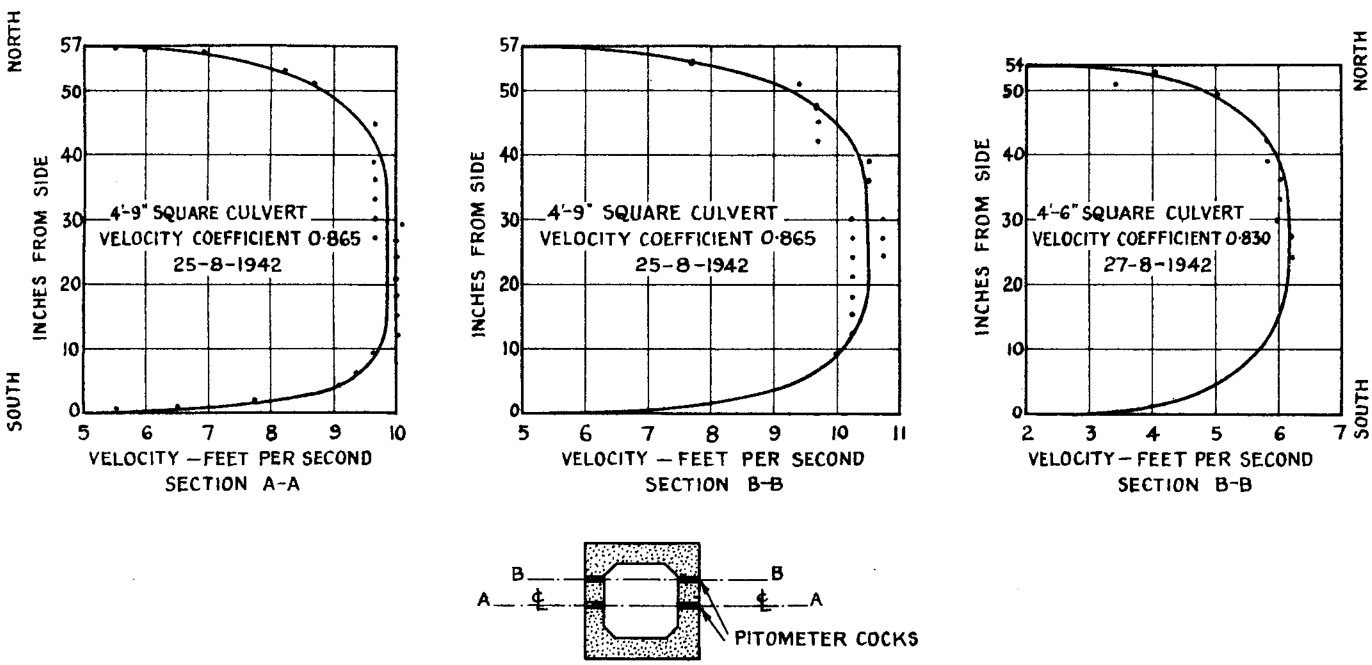


FIG. 46

VELOCITY DISTRIBUTION CURVES FOR COOLING WATER INLET CULVERTS AS MEASURED FROM PITOMETER TRAVERSES AT LITTLEBROOK POWER STATION (KENT ELECTRIC POWER Cº)

(BY COURTESY OF SIR ALEXANDER GIBB & PARTNERS) matic recorders. Unfortunately, at the time, the experiments could not be extended to beyond the condenser, and hence it is not possible to say whether these " jerks " of pressure are felt beyond the condenser, or whether they are damped out in the condenser. The danger of the negative wave lies in the fact that, if the top of the condenser is situated near the absolute hydraulic gradient line, siphonage may be interrupted temporarily, and if the negative wave is propagated beyond the condenser, then the outlet culverts are subject to an increase of external loading. Such jerks may be instrumental in loosening condenser tube packings.

A series of readings were taken to derive a value for the friction constant of these mains. For f, the constant to be used in the formula, $H = fv^2/2gR$, the average value worked out at 0·0075. Expressing this in terms of Williamson's formula (29), the value for " n " worked out at 0·0165. The values are high, due to the fact that transition and bend losses had not been deducted, so that the actual friction constants are somewhat below this. Referring to Table 12 it is seen that, even so, the value of 0·0165 is of the order of Williamson's constant for rough concrete, i.e. 0·017.

Photograph 4 shows a typical transition, where a square concrete culvert changes to a circular bus main which had been gunited as previously described. The photograph shows the surface conditions for the culverts which had been under test at Littlebrook Power Station as described above.

Fig. 48 shows typical hydraulic gradients as recorded by the series of gauges (see Fig. 45) for Littlebrook Power Station. Using the condenser and pipe constants together with pump and tidal data, it is possible to check that siphonage is maintained at all stages of tide and load.

The question of siphonage is dealt with by Guy and Winstanley (20) who maintain that a quite unnecessary air of mystery surrounds the problem of siphons with legs longer than 25 ft, and they suggest that, with a well-designed and air-tight system, it is possible to maintain a siphon greater than that of the barometer, *if there is sufficient friction in the discharge pipework*. The effect of the friction in the discharge pipework is to increase the pressure at the top of the siphon by an equal amount.

The siting of the condenser will, therefore, be done, bearing in mind that the Turbine House excavation must be a minimum and that siphonage must be possible at all stages of load and tide. Attention should be given to the amount of friction to be expected from the outlet culverts in order to make sure of siphonage where a given selection results in a borderline case.

It must be borne in mind that friction is a function of velocity as well as length, and that capital saving may be affected by increasing the former instead of the latter.

More consideration could also be given to the avoidance of head lost due to transitions or bends. It should be a simple matter to design square valves which could be incorporated in a square bus main, thus avoiding the necessity for transitions.

3. Pumps and Pumphouse

A grouping of pumps may be as shown in Fig. 29b, utilising the characteristics given in Fig. 29a and bearing in mind the " range " effect of station requirements. Thus, the cooling water required for a generation of 48 mW will be different if generated by two 30 mW sets than when generated by one 60 mW set, and so forth. Some engineers advocate the splitting of pump sizes into 60–40 per cent capacities.

The vertical spindle type is usually preferred on account of the smaller space requirements and the separation of motor and pump which is possible where dangers of flooding exist. Difficulties are the exact settings required and the avoidance of whip in the long spindles. Priming is avoided by having the pumps permanently drowned.

Gravity should be permitted to do as much as possible of the work, compatible with other requirements, and the pumphouse would generally be placed as close as possible to the Turbine House. This is not always practicable and provision often has to be made for the construction of pumphouse foundations, etc., closer to the river.

Where great tidal variations are prevalent very deep excavation problems may have to be faced, involving heavy investments. Problems that require attention as regards possible economies are :—

(1) The heads and pressures that coffer-dams would have to withstand during construction periods. The system of temporary bracing adopted must cater for these pressures and yet be roomy enough to allow work to be carried out at high speed.

(2) When sited close to a river or the sea, the strata may be such as to lead one to expect great quantities of water to be dealt with. In a few instances it has been possible, owing to the nature of the subsoil, to lower the ground water table for the period of the work, by means of the well-point methods (39) and (40). It may be possible to drive sheet piling into impervious strata and thus to cater for surplus face water only. The vertical type pump which can be hung up and moved about at will would seem to be the best for this type of temporary work.

(3) The sealing off of the face of the excavation when completed should receive careful consideration. No pressure must be permitted to build up under the concrete seal before it is sufficiently strong to take this uplift. Consequently a system of drainage must be devised to enable the accumulating water to escape. The simplest system of sealing off such slabs is to include valves in the concrete slab, through which the water, collected by a system of drains under the slab can escape until such time that curing has sufficiently advanced and the requisite weight has been placed to counteract uplift. The valves are then closed and sealed by concreting in.
Such thick slabs offer opportunities for savings by using " plums." Pile " cut-offs," usually a dead loss except perhaps as kentledge, may be used for this purpose.

War experience in connection with the prefabrication of movable structures for turbo-alternator protection against air raid damage, has shown that the principle could easily be applied to other machines. In a pump house it is merely necessary to weatherproof the motors and sundry panels. The revolving screens, sluice gate motors, etc., in many cases already operate in the open air. The provision of a superstructure of sufficient height to contain the crane and permit the withdrawal of motors, etc., seems a waste of space which costs anything between 10d. and 2s. per cu. ft. (Fig. 49a). It would seem possible, either to prefabricate light, weatherpoof structures which can be transported by the cranes when required, and which cover the motors or panels or entrances to pump chambers, etc., or to build such structures by ordinary construction methods and provide movable hatchways which would ensure access to the machines by the cranes, as shown in Fig. 49b. Apart from the saving of cost of space and such refinements as doors, windows, louvres, etc., with attendant maintenance, there is an incremental saving of weight on foundations. These light structures could be of any shape desired and all could be made to blend with the general tone of architecture adopted, and lighting and ventilation problems could be overcome easily. The cranes would operate in the open, but attention must be given to facilities for the removal of pumps, valves, etc.

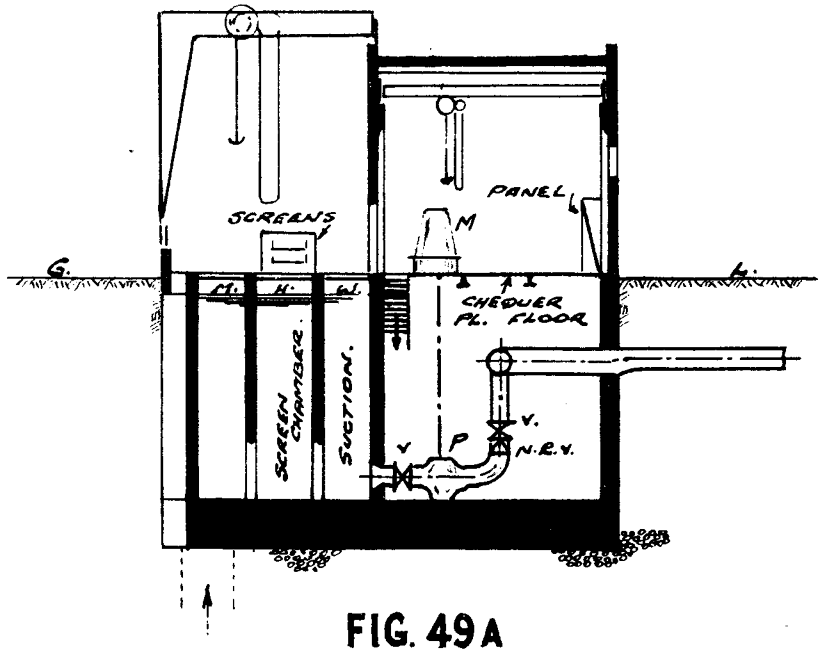


FIG. 49A

TYPICAL MODERN PUMP HOUSE WITH SUPERSTRUCTURE

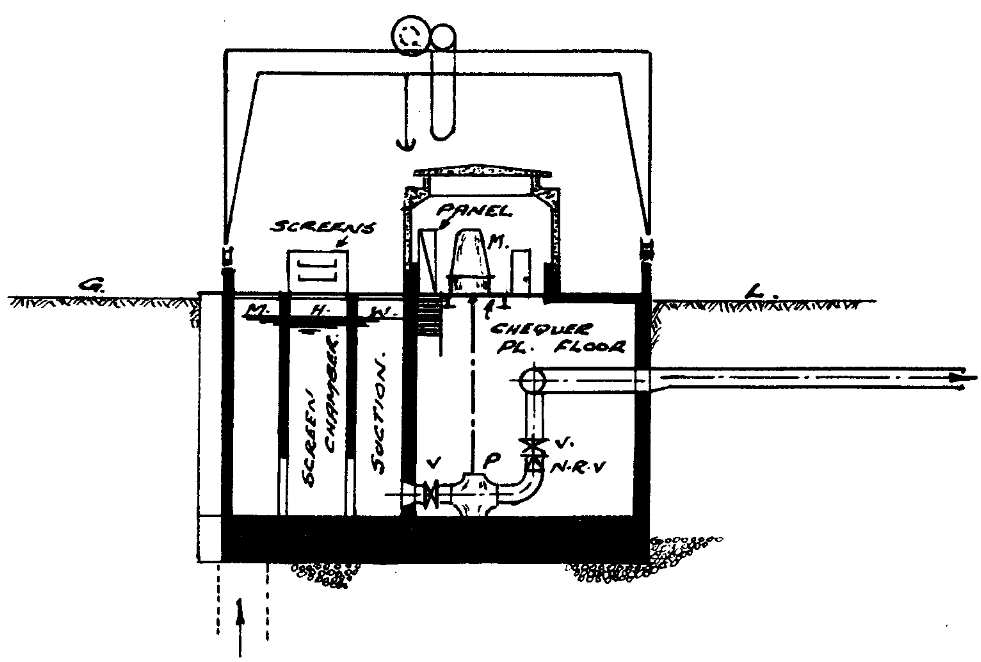


FIG. 49B

SHEWING PROPOSED MODIFIED (UNIT PLAN) SUPERSTRUCTURE MADE ENTIRELY REMOVABLE OR PROVIDED WITH HATCHES AS SHEWN, TO FACILITATE WITHDRAWAL OF MOTORS, PUMPS, ETC.

4. Inlet and Outlet Works

It is impossible to cover these works by general notes as the type and nature of the works depend entirely on site conditions. Local authorities such as Conservancy and Port Authorities, Fishing Societies, etc., may exert a marked influence on design.

Neither entrance nor discharge velocities should be such as to cause scour or damage. Where intake works are situated very near or under jetties (usually to avoid building special protection works) attention must be given to the phenomenon of silting, which is very marked under such piled structures, and which may cause silting up of conduits and tunnels, or give rise to abrasive material being carried through the culverts with consequent early deterioration to them. If this cannot be avoided, care should be taken to avoid construction methods which increase this silting, such as large numbers of timber piles driven for construction purposes by the contractors, which, more often than not, cannot be entirely removed again at the end of the contract.

Where inlet or outlet works are sited independently of other structures they will have to be protected, and protection must be sufficient to withstand mooring stresses, as it is a practical certainty that these structures will be so used, and in any case, in a navigable river bumps or blows must be expected.

The amount of water flowing in the river at low flow periods, and the amount which it is proposed to use for condensing purposes and to discharge into the river again at a higher temperature all have an important bearing on the relative spacing of inlet and outlet works in an effort to avoid re-circulation. As a practical example—on the Thames—the Fulham outlet is situated 420 ft downstream of the intake works.

The outlet works (especially in tidal rivers) is usually placed outside the stream line flow in line with the intake works. Attention may also be given in design where river water is not plentiful at low flow to the greater diffusion of hot water and to discharging same at a slightly higher level than that of the intake works.

Where it is intended to construct a sump for receiving miscellaneous drainage discharges, sewage effluent, etc., prior to its entering the outlet works, provision must be made for trapping out ash, dust, grit, etc., and which can then be grabbed out or otherwise disposed of.

CHAPTER V

THE FUEL CIRCUIT

A. Coal Fuel

We have previously noted, in Chapter 1, how in 1932/3 the average generating costs exclusive of capital charges, for all the authorised electricity undertakings were 0·214 pence per unit generated, of which 0·137 pence or 64 per cent represented fuel. Referring to Figs. 4 and 5 it is seen that this figure is still in excess of 30 per cent. It is therefore easily appreciated why this circuit should be given a high priority in the planning stages. But suggestions emanating from the civil engineer in accordance with the principles of the straight line stated in Chapter II must take into consideration the requirements of the mechanical engineers, whose interests are interwoven with this circuit at all stages.

This circuit is most subject to the demands of " Continuity of Service." Thus, coal storage space is required as insurance against strikes or failures of service ; conveyors are in some cases duplicated ; provision is made for taking in coal by rail and/or road as an alternative to water-borne coal ; gravity bunker storage is required against failure of conveyors ; ash pipes are duplicated ; alternative means of ash disposal are provided. (In the case of Battersea (15) emergency tip wagons operating on a 20-in track in the basement were provided to receive quenched ashes.)

A further feature has been introduced since 1939. Up till then graded coal was received by the British stations, and grinding was carried out for the pulverised fuel units only. During the war, however, national needs and the exploitation of outcrop coal have made it necessary to accept run-of-mine coal with the result that crushers had to be installed on the sites. The system has worked so well that it is likely to remain. It is possible that the carrying capacities and length of life of the conveyors may be affected, and when crushers are sited this must be done with a view to minimising the above effects as far as possible.

Fig. 50 shows a diagrammatic arrangement of a typical fuel circuit. One glance shows how important are the principles of the straight line energy theorem to the planning of this circuit, and how these principles apply for all three dimensions—height, width and length.

Any suggestions involving the increasing of the height of the circuit means an increase, not only in operating costs due to the fact that the station supply of coal must be raised against gravity through this extra height, but also of the costs of foundations and buildings. And the co-ordination problems are increased since, during construction, the erection time will be lengthened, and weather-proofing will be delayed, which means that it will be correspondingly longer before plant contractors may be deployed for erecting fans, crushers, pumps, pipes, etc.

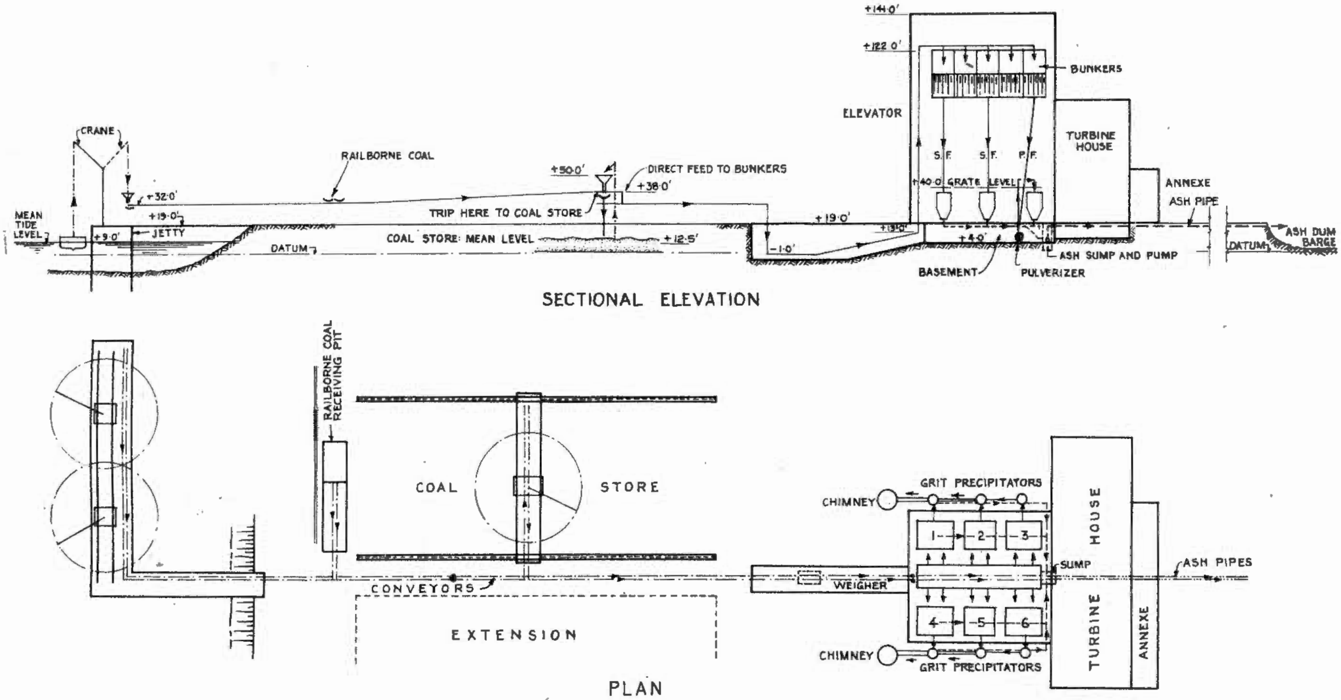


FIG. 50A

DIAGRAMMATIC ARRANGEMENT OF TYPICAL COAL FUEL CIRCUIT

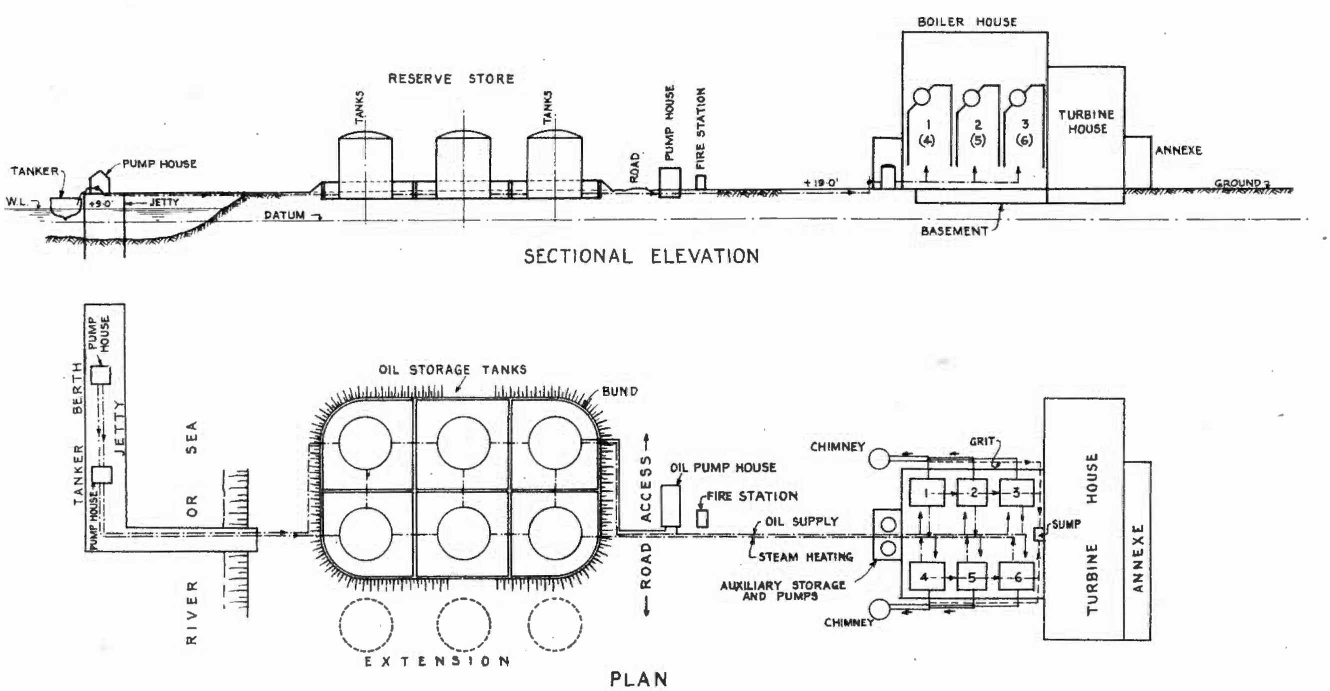


FIG. 50B

DIAGRAMMATIC ARRANGEMENT OF TYPICAL OIL FUEL CIRCUIT

Similarly the ash sump should be in the line of motion of energy, for any other siting will lengthen all trenches and conduits and will increase maintenance costs apart from the fact that the layout becomes complicated if not confused.

With regard to coal, the belt conveyor has become accepted almost universally as the best method of conveying the coal. For it there is claimed the following advantages :—

(1) Very simple of construction and few working parts which require the minimum of maintenance, and replacements are easily made and adjustments are straightforward and simple. (Tensioning of belts, etc.) Erection is easy, particularly when they are so constructed that trough sections carrying the idlers can be bolted up easily, and the weights being such that a section can be handled by two men.

(2) Adaptable. Bolted up sections could be made to follow the configuration of the ground, and mobile units can be used for all purposes. The " troughed " type idler system is popular, not only because of the increase in carrying capacity, but because loss of fine materials is minimised for open conveyors.

(3) Very light foundations required. Supports usually of lightly braced structural steel members. This enables the principle of " multiplicity of function " to be exploited to the full. Thus a bent of two piles, specially driven to support conveyor stanchions and each capable of supporting 60 tons, say, would have a supporting power in excess of possible practical spans. But existing foundations could be used to support such light additional loads with small extra cost.

(4) Small horsepowers required. The motors are manufactured for open air work. Measured values of horsepower for different lengths of conveyors running empty and full, are shown in Fig. 51, which illustrates that horsepower is directly proportional to length of belt, both empty and full, the equation for this size of conveyor being :

$$\text{h.p.} = 6{\cdot}4 + 0{\cdot}0124 \times \text{length (ft).}$$

(5) Easily adapted to gradients. The maximum gradient at which belt conveyors can operate without the material slipping depends on such factors as shape, size, and assortment of material and feeding arrangements, i.e. whether continuous or intermittent. Table 14 gives permissible gradients with typical materials common to power sites.

TABLE 14

PERMISSIBLE INCLINES FOR BELT CONVEYORS (41)

MATERIAL	CONDITION	SLOPE—DEGREES
Coal—Anthracite	Sized	16–17
Coal—Bituminous	Run-of-mine	18
Coal—Bituminous	Slack	20–22
Coal—Bituminous	Slack—moist	22
Coal—Bituminous	Sized—small	17–18
Coal—Bituminous	Sized—large	16–17
Coke	Run-of-oven	18
Coke	Screened	17
Coke	Breeze	20

It is noticeable that the best gradients are obtainable with moist slack.

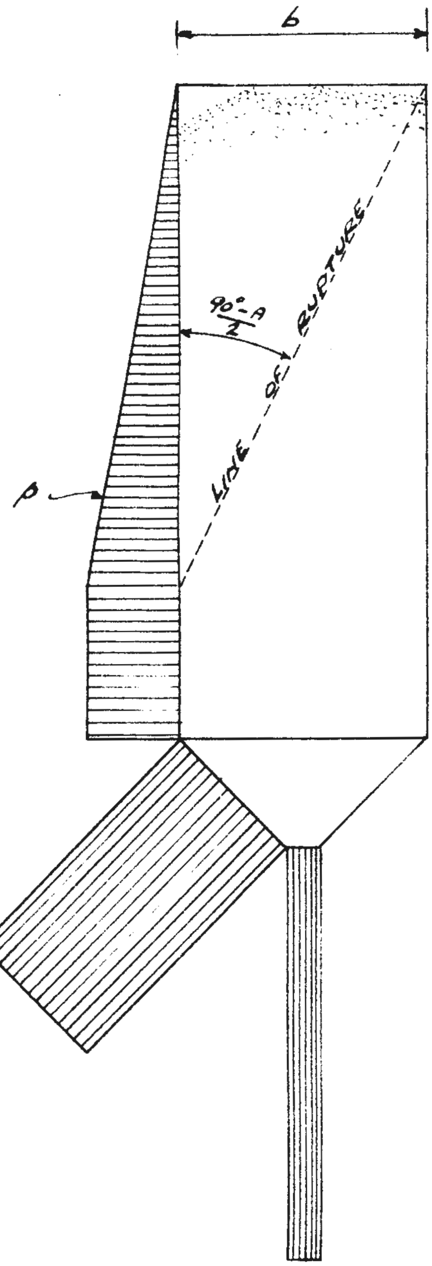


FIG. 52A
TYPICAL PRESSURE DISTRIBUTION
DEEP BUNKERS

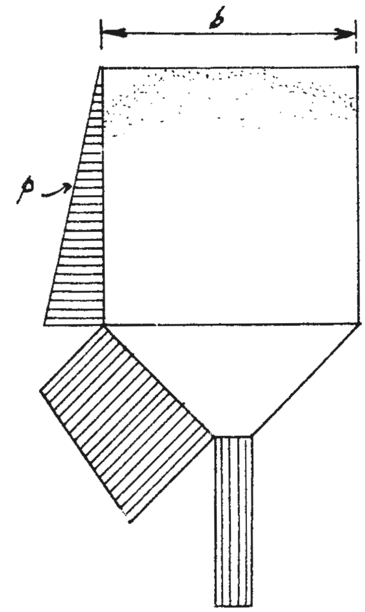


FIG. 52B
TYPICAL PRESSURE DISTRIBUTION
SHALLOW BUNKERS

FIG. 52

TYPICAL PRESSURE DISTRIBUTION DIAGRAMS
FOR COAL BUNKERS

again to the firing floor then to be dropped to the ash sump again, and finally to be pumped up to a barge, truck or ash dump.

For P.F. plant this untidy circuit could certainly be cleared up; whether by outside low-level bunkers feeding pulverisers situated on or nearer firing-floor level, or by lowered internal bunkers is a matter of choice and calculation only.

This argument has never received strong support from the operating angle for the simple reason that belt conveying is so cheap, both in first cost and in operation. Thus if the bunkers in Fig. 50 were lowered by 40 ft, say, the saving in the 40 ft of conveyor or elevator length would not amount to much, and the saving in operating horsepower for, say, a 300 mW station steaming full out at 1·2 lb per kWH in lifting through the reduced height amounts to only about 8 h.p. ! This would mean a saving of approximately £65 per annum at 100 per cent plant factor ; cost of electricity, 0·33d. per unit.

But considering the saving in building space at the Battersea figures for boiler house superstructure, i.e. 10·29d. per cu. ft. (15), assuming bunkers 30 ft wide by 300 ft long, the capital saving, in addition, amounts to :—

$$£\ \frac{300 \times 40 \times 30 \times 10{\cdot}29}{240} = £15{,}400.$$

The question of time element enters the picture as well. Stanchions need be shorter and lighter and could be erected at greater speed, not to mention the easing of transport and of storing facilities, and of maintenance of columns and painting. It might even be possible to make use, in the case of S.F. boilers, of the small horsepowers and low unit costs of belt conveyors in order to utilise these for feeding purposes instead of gravity, which has to be bought at the cost of horsepower elsewhere, and of building space. Such conveyors could possibly be duplicated or even made mobile in the interests of continuity of service.

Where it has been decided to have basements the Civil Engineer would welcome the more efficient use of such basement space. In the first place it must be decided that it is cheaper to form a basement than to backfill, say. But having decided that this is so and the basement is formed, there still arises the problem of efficient use of the basement space provided. Up to now the bugbear of flooding has prevented the full use of basement space below possible flood levels. Yet it is here that the Civil Engineer can make a great contribution.

It is no impossible matter to waterproof structures which are suitably designed, and most structures on power sites bear witness to this. The problems are somewhat as follows :—

(i) The actual wall thicknesses and concrete mix ratios required for full water-proofing so that damp does not enter the buildings. Co-operation would be needed from electrical engineers in that cable ducts, etc., would have to enter from above possible flood levels.

(ii) The treatment required to make the concrete impermeable against moisture (especially of a saline character) which would attack reinforcement and cause deterioration of concrete. Attention would similarly be given to the presence of sulphur compounds present in such materials as ashes.

(iii) The control of shrinkage which may cause cracks which would by-pass achievements under (i) and (ii) above.

These problems will be referred to in more detail later on under Foundations, but assuming that waterproofing is guaranteed, the advantages accruing become numerous. A few are tentatively listed below :—

(*a*) Thus ash sumps and whirlpools could be constructed in units in such a position under the quenching hoppers that all ash and grit sluicing trenches are reduced in length. The forming and operation of these trenches is an expensive process. The abrasive character of ashes and grit calls for special cast iron linings and target plates (at corners and junctions) for these trenches, all of which require frequent inspection and renewal. Similarly the ash, hydrojet and re-circulating pumps could be situated conveniently and, with suitably laid out cooling water mains passing close by, the intake pipes could be much reduced, thus saving capital outlay, operating cost of pumping against friction, and maintenance renewals of piping subject to corrosion from, say, sulphur compounds : all in accordance with the principles of straight line energy. These sumps, which are usually of reinforced concrete if constructed independently outside the main buildings, have to be waterproofed anyway, and have to carry their own overheads as regards temporary construction methods, such as pumping or cofferdam works. It therefore stands to reason that unit costs will be reduced for construction in a formed basement. At any rate, the matter should be considered.

(*b*) Assuming the disposal of ash is by pressure pumping, the duplicate ash pipes could be carried for a long way on existing foundations with small incremental cost for trenching. This facilitates inspection and the frequent turning of such pipes which is necessary due to excessive wear, and avoids frost troubles, and failures of cast iron pipes due to uneven settlement.

(*c*) Surplus space could be utilised for storage of materials, including electrical plant, thus saving superstructure space elsewhere. The designs have to bear in mind, however, the getting into and out of the basement of unwieldly storage articles.

A simple system of heating and ventilation could be designed to ensure the comfort of the operators—and insulation against noise is easily effected by suitably designing the floor above.

The trend to site chimneys well clear of the boiler house structure has recently shown a tendency to swing the other way again. It has been realised that the deviation from the principles of " straight line energy motion " has caused increased costs for ducting, greater fan horsepowers to cope with increased " draught " friction required, and more maintenance on longer grit trenches, etc., thus nullifying to a large extent such advantages as were originally claimed for this procedure.

It is possible that in post-war years attention will be given to incorporating ash jetties (where provision is made for sea disposal of ashes) with the coaling jetties in an effort to reduce civil engineering capital costs. Timber used in the construction of ash barge jetties, from the point of view of length of life, rather handicaps the structure in comparison with the more durable concrete structures common for coaling jetties. Maintenance charges tend to commence earlier and increase more rapidly than in the case of concrete jetties. There exist few sites where precautions need not be taken against marine borers, such as " Teredo."

The overall cost of the concrete coaling jetty, including for an R.C. approach at Littlebrook Power Station, worked out at approximately £2·14 per sq. ft. of actual jetty deck. For the timber ash jetty the corresponding figure amounted to £2·32 per sq. ft. of jetty surface. In both cases the approaches caused a heavy " loading " of this figure. By combining the two it becomes possible to eliminate the double approach sections. Moreover, by using the practice of setting rails flush in concrete surface, the rail approach could be utilised for road approach as well in the combined system, so that no appreciable increase in width would be desired.

The increase in width for such a combined jetty would ensure that greater mooring loads could be taken, and hence either foundation loads could be reduced by the greater spreading, or, alternatively, larger colliers could be accommodated in accordance with Tersaghi's formula (Fig. 19), which has already been discussed in Chapter III.

Typical values for ships and velocities of approach for which fendering and jetties have been designed are given below for purposes of reference (42) :—

2,800 tons displacement	15 ft per min (Wandsworth) Kinetic energy 2·75 ft tons.
5,000 tons displacement	12 ft per min (Tower Bridge) Kinetic energy 3·13 ft tons.
10,000 tons displacement	10 ft. per min (Purfleet) Kinetic energy 4·35 ft tons.
12,000 tons displacement	60 ft per min (Northfleet) Kinetic energy 187·0 ft tons.

All for vessels under control.

B. Oil Fuel

It is not intended to include in this work an argument setting out the rival properties, merits, or costs of coal and fuel oil as a means of generating steam for electricity.

The Civil Engineer is interested only in so far as these materials affect the construction, and methods and costs of construction of civil works.

Applying the Straight Line Energy Theorem only, that is, without other considerations, there is no doubt that fuel oil is the better material since the flow circuit can be simplified at all stages, vertically as well as horizontally.

At the beginning of the circuit reception is simplified. Oil is brought into the site by tankers, i.e. road or ship, and is delivered to the terminal from whence it is pumped to the main storage tanks. Instead of conveyors to this reserve store, pipes are used. This introduces prefabrication in a healthy manner, because pipe sizes are usually small, and they can be stacked neatly until required, or brought on to the site as required, and consequently site labour is reduced and less working space is required. These pipes are usually buried or covered, thereby making available " site surface " to be utilised for other functions and hence increasing design density (megawatts per acre).

Reclamation cranes or other reclamation gear, and the attendant foundations and auxiliaries are eliminated.

The main reserve storage is usually by means of a battery of steel tanks, each one supported on firm foundations set into the ground and having an earth or concrete bund built around the tanks in such a manner that, if the oil should be lost through some cause, the bund would retain the oil and prevent its spreading over the site.

Generally, for high flash point oils (furnace and gas) bund capacity is 120 per cent of the tank capacity (single tanks), or 120 per cent of the capacity of the largest tank in the bund (grouped tankage).

As a general rule the following safety distances apply in hot territories :—

Between tank shells	10 ft
Between tank shell and boundary wall	25 ft
Between tank shell and pumping equipment	15 ft

These tanks may be welded. Thus standard sections could be brought on to the site ready for welding, thereby economising in site labour and space.

From the reserve store tanks the supply pipes lead direct to the auxiliary service tanks in the boiler house, and so to the boilers. These pipes are usually put into the same trench as special steam pipes, the purpose of which is to keep the oil flowing easily in very cold weather.

In the boiler house the overhead gravity bunkers (for coal) are eliminated, and the energy circuit is straightened out considerably. There is saving of boiler house space, and consequently foundations and columns are reduced. Coal conveying machinery, elevators, weighbridges, etc., are also eliminated, and simple pipe distribution is substituted. These may be carried as an incremental load on existing foundations without special design considerations apart from those of attachment.

The ash circuit is practically eliminated. Whereas coal has an ash content of the order of 9 to 12 per cent, that of medium fuel oils is of the order of 0·1 per cent. Thus ash hoppers, trenches, ash sumps, whirlpools, ash pumps and special cast iron pipes are completely eliminated. (Assuming water-borne ash disposal.) Moreover, the setting aside of a large area of land for ash disposal, or, alternatively, the operating cost involved in other means of disposal is avoided.

From the point of view of the civil engineer fuel oil is therefore the better medium of the two for steam production purposes, because of the two fuel oil lends itself more to the adherence in design to the principles of the Straight Line Energy Theorem, leading to major economy in civil engineering costs.

But of course there are other considerations to be taken into account. Oil is not found in every country. When arriving at master economy, it is no use whatever reducing the civil engineering costs, i.e. rotating the " fixed charges " line in a clockwise direction, as shown in Fig. 15, if the net saving, or more than this saving, is added on to the operating costs curve. Total economy is, or should be, the aim. The cost of the fuel delivered at the power station is a major determining factor in the selection of the fuel to be used.

Strategic considerations, in the interests of continuity of service, also have a large influence in the matter. Is the oil supply line likely to be interrupted due to strikes or revolts n the country of origin, or strikes among shipping crews ? Is the supply likely to be cut off in war ? Are prices liable to fluctuate—and in an unpredictable manner ?

In Great Britain fuel oil is not used to any large extent. Table 16 shows what a small part fuel oil plays in the production of electrical energy in Great Britain.

TABLE 16

COMPARISON OF FUELS USED IN THE PRODUCTION OF ELECTRICAL ENERGY IN GREAT BRITAIN, 1935-46 (60)

Material	THOUSAND TONS											
	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946
Coal	12,236	13,603	14,763	14,927	15,925	18,112	20,435	22,283	22,599	24,074	23,493	26,201
Coke	175	168	213	183	235	258	275	320	318	337	330	378
Oil	24	24	24	20	19	26	20	18	14	18	20	34

CHAPTER VI

GENERAL NOTES:
FOUNDATIONS, BUILDINGS AND CONSTRUCTION

A. Foundations

For modern stations the medium of construction as regards foundations is almost exclusively reinforced concrete; the only extensively used building material that is manufactured " on the site."

Much research has been carried out recently in Britain, Europe and America —with a view to studying methods for improving the quality of concrete for all purposes, and the following brief review of discoveries and opinions may serve as a ready reference or a guide for the many and varied problems facing the Power Engineer :—

(1) *Permeability of Normal Portland Cement Concrete*

" The influence of water content (water/cement ratio) is very marked in the early stages of the life of concrete and decreases with age, and is greater with lean mixes, decreasing as the proportion of cement is increased.

" Cement and water are of approximately equal importance as regards the influence on impermeability.

" The rate of decrease of impermeability is dependent upon the cement content ; thus with two mixes of equal maximum permeability, that having the greater cement content will decrease in permeability at the greatest rate. The careful proportioning of aggregate is of much less importance than the use of correct quantities of water and cement.

" The sand content plays a greater part in the determining of permeability of a mix than the gravel content. See also Fig. 53.

" Curing conditions play a very important and fundamental part ; the influence being greater than any of the other factors concerned. The best concrete is obtained by storing in water, and the nearer conditions approach to this the more impermeable the product. The days immediately following the mixing are the most important."

The quotation is from " The Permeability of Portland Cement Concrete," Building Research Technical Paper No. 3, by Dr. W. H. Glanville.

(2) *The Deterioration of Concrete in Sea Water*

The following are sundry conclusions by Dr. R. E. Stradling, C.B.E., M.C., D.Sc., Ph.D., M.Inst.C.E., after tests carried out over a period of five years, described in " The

Deterioration of Structures in Sea Water," 15th Report, 1935 (33) ; the specimens referred to having been designated :

Rich mix = 1 : 0·87 : 1·73
Medium mix = 1 : 1·67 : 3·33
Lean mix = 1 : 3 : 6 (All by weight)
Dry mix = ½ in. slump
Normal mix = 2 in. slump

" Where 2 inches cover of concrete was provided over the steel reinforcement medium mixtures offered a good protection against corrosion of reinforcement.

" Of the cements used none showed any special advantage.

" The addition of trass in the case of lean mixtures proved advantageous. Reinforced specimens with this addition showed few or no signs of deterioration.

" A dry mixture proved slightly superior to the wet mixture, but the difference was not well defined. Practically no cracks were observed on the trowelled surface of the test pile owing probably to the increased impermeability of the concrete due to trowelling.

" Cracking nearly always occurred after signs of rust have appeared on the surface of the concrete and it would seem therefore that the permeability of the concrete is responsible. The deterioration of the piles was generally due to the rusting and consequent expansion of the reinforcement causing cracking of the concrete rather than the attack on the concrete by the sea water. The deterioration of the piles as shown by cracking of the concrete occurred with few exceptions, and in the cases of all mixtures, above water level. (The area between wind and water.)

" The tests made with small cylinders have not given any guidance as to the cracking of reinforced concrete piles. Except with lean mixtures the concrete of the test specimens was not materially affected.

" The experiments indicated that the concrete cover, so far as practicable, should be impermeable, and that for the medium mixtures this could be obtained with 2 in. cover."

Both the above considerations (permeability and deterioration, etc.) are extremely important to the engineer in planning foundations to power works, and partcularly if these are to be located near sea water.

Thus in piling for jetties the question of hair cracking affecting the life of the structure and its future maintenance requires careful consideration. It has to be borne in mind that pile driving causes hair cracks to develop in the upper three or four feet of pile, which may form the starting points for penetration of sea water and thus of deterioration. British practice usually insists on breaking down and stripping the heads of piles for a sufficient length to provide grip length of reinforcement. This practice also avoids then the possibility of exposed cracks in the area between wind and water. The making good is done with a rich mix with due regard to the cover requirements mentioned above. The practice of casting piles with grip lengths of bars projecting above pile heads is to be avoided on this score, and apart from the fact that special dollies are then required for driving, and the disadvantage that piles must be driven exact to level.

Similarly, whenever possible, three- or four-point lifting of piles must be avoided. Unless lifting gear is carefully designed and supervision most strict, it is possible that the

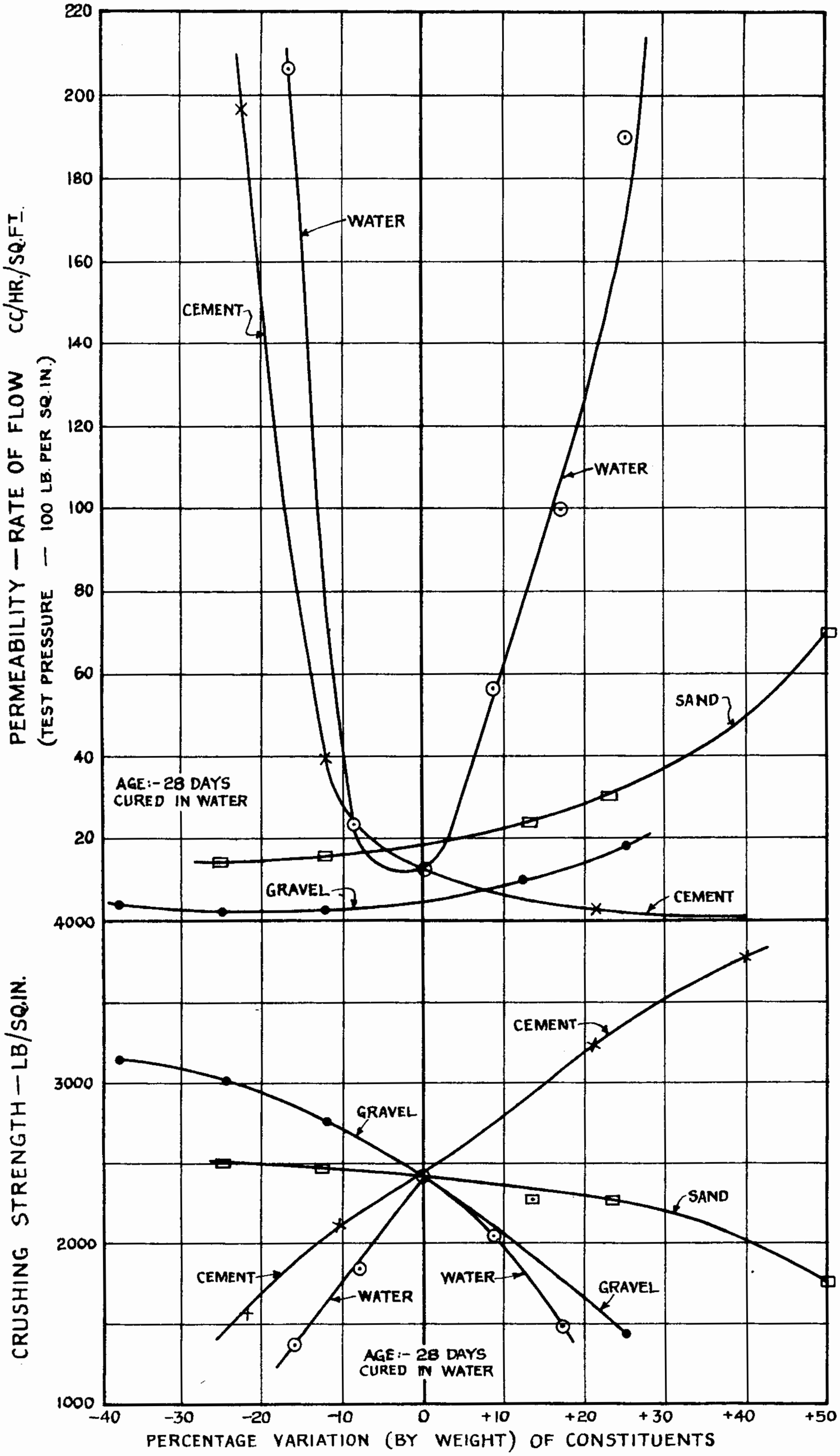


FIG. 53

RELATIVE INFLUENCE OF VARIATIONS OF CONSTITUENTS OF A 1 : 2 : 4 (BY WEIGHT) CONCRETE MIX

(FROM..............43)

pile, whilst designed for three—or more—point lifting, will actually span two-point, and hair cracks will develop. The practice of reinforcing one side only to cater for lifting purposes—a petty attempt at economy—usually results in cracks developing due to oscillations of pile during transporting, which cause reversals of stress which had not been catered for. On a site it becomes a very difficult matter to guarantee smooth handling during transportation and pitching of piles. What use are these " economies " if the life of a jetty costing, say, £2 per sq. ft. of surface, has its life reduced from, say, 25 years to 10 years ?

In jetty design the beam arrangement should be such as to avoid " dead " pockets of air close to the water surface, and similarly sharp corners should be generously chamfered or filleted.

(3) *Deterioration of Concrete due to Mechanical Action of Running Water*

The following symbolic equation denotes the action of water on concrete :—

$$Ca\,O \cdot Si\,O_2 + H_2O = Ca\,Si\,O_2 \cdot H_2O = Ca\,(OH)_2 + Si\,(OH)_3$$

and represents a state of equilibrium. Thus if $Ca\,(OH)_2$ is removed by running water, then further decomposition of $Ca\,O \cdot SiO_2$ occurs (44).

(4) *Effects of Peaty Water*

The organic acids, humic, acetic, formic, glycollic and oxalic, associated with peat and moorland water, attack normal Portland cement concrete much more rapidly than concrete of aluminous cement, and seem to accelerate the action above, under (3), dissolving lime and calcium aluminate (44).

Of the constituents of cement, tricalcium aluminate is the most vulnerable to attack in sulphate bearing waters.

Recommendations resulting from these experiments at Kinlochleven (44) were :—

(*a*) That cement should be finely ground.

(*b*) A rich mix should be used.

(*c*) Aluminous cement should be used where possible. High grade aluminous cement showed no signs of deterioration after exposures of 6½ years to acidic moorland water.

Such considerations raise the problem of protective facings for concrete surfaces exposed to such attacks. Typical examples are :—

(*a*) An outer layer of richer concrete placed simultaneously with inner hearting (45), (46). The use of aluminous cement in such facings, where water is acid or contains sulphates, is desirable.

(*b*) The use of a facing as in (*a*) but applied with a gun. Precautions have to be taken to ensure that water does not get under this " skin." Thus, this method should not be used where running water is present over the faces to be treated. The trowelling of gunned surfaces adds considerably to the impermeability of the layer. The method requires an extra operation, but the cost may be justifiable.

(*c*) Masonry facings (46), (47), or metal sheets (48). Both methods expensive and involve a time factor.

(*d*) Against moorland water attacks the following have been tried (44) :—

- (i) Slurries applied superficially—limited thickness and short lived.
- (ii) Tars and bitumen coating—limited life.
- (iii) Penetrative treatment by aqueous fluids, e.g. sodium silicate, etc.—protection for a limited time only.

(iv) Double surface treatment by an insoluble salt precipitated in the pores of the concrete by two successive applications. (No comment was made on the results.)

(v) The use of oils and bituminous emulsions.—With emulsification results were encouraging as regards existing acid water.

(vi) Incorporation of materials in concrete.—Fat oils and tars reduce strength, but finely powdered blast furnace slag, for instance, often showed improvement without any loss of strength resulting.

(vii) Staffordshire blue brick facing.—Other than aluminous cement the only material which showed no change in condition after six years' exposure.

(5) *Heat Evolution and Shrinkage of Concrete*

Heat is evolved during the first three days by the constituents of cement in the following order (49) and (50) :—

(i) $3\ CaO \cdot Al_2O_3$.

(ii) $3\ CaO \cdot SiO_2$ (Considerably slower).

(iii) $4\ CaO \cdot Al_2O_3 Fe_2O_3$ } Relatively small value of almost equal amount.

(iv) $2\ CaO \cdot SiO_2$

High alumina cements evolve heat very rapidly during the first 24 hours and the temperature rise in a mass of high alumina cement in the early stages of hydration may be double that obtained in a similar mass of rapid hardening Portland cement, though the ultimate amount of heat evolved during setting is not necessarily very different (51).

Maximum temperature possible with a particular cement would be obtained about 4 ft below the radiating surface (49).

This would seem to require careful specification of cement if shrinkage stresses are to be avoided. A British Standard Specification for Low Heat Cement is in draft, but not completed yet.

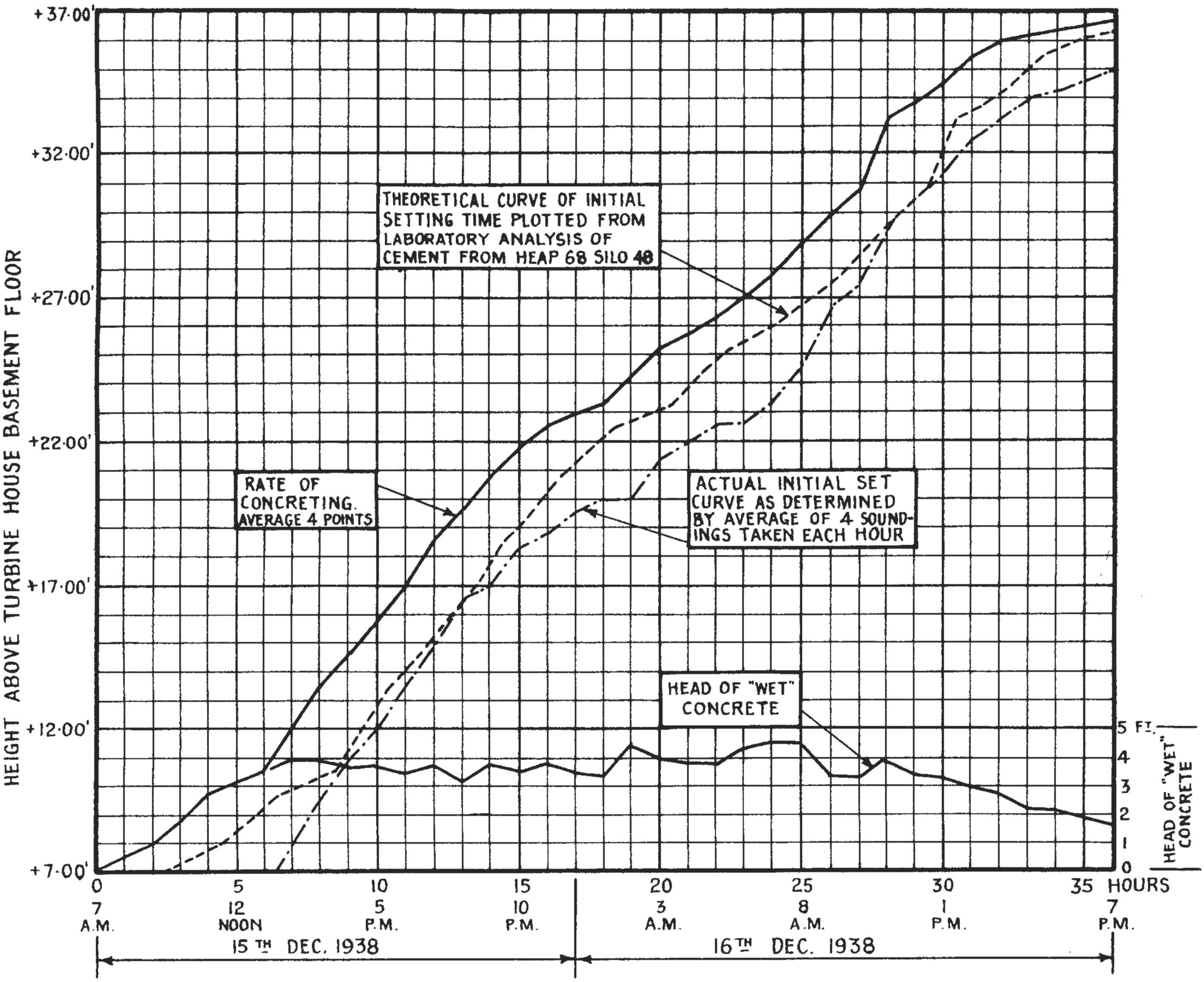
Fine grinding of cement has a much less pronounced effect on heat hydration than on strength (52). It results in quicker setting and therefore increased temperature rise at the early stages, and separation of water from concrete during vibration is reduced (50).

Specification of chemical composition and fineness is stressed in the U.S.A. (52).

Heat evolved increases with increase in water content up to a maximum and then declines. With neat Portland cement this maximum occurs with about 25 per cent mixing water (49).

There would seem to be a trend towards the use of Portland-Pozzolanic cements. There is less tendency for water to separate when vibrators are used, as compared with other types of cement. Hardening at low temperatures is slow. These cements are more impermeable, more resistant to freezing and thawing and to the action of sulphate waters than those containing all Portland cement. They are useful where concrete is liable to be attacked by sea water. Their effects are due to active silica combining with free lime that is free in the cement or liberated in the setting process (53) and (54). (Building Research Technical Paper No. 28, dealing with mixtures of Portland cement and Pozzolana, is still in draft.)

Completely watertight structures have been built with no contraction joints, e.g. the pump houses at Barking and Littlebrook power stations, using ordinary Portland cement (rich) mixtures. The wall thicknesses being of the order of 2 ft 6 in thick prevented the introduction of high evolution of heat and differential cooling, and thus of relative shrinkage.



CONCRETE DATA

TYPE "D", HEAP 68, SILO 48
INITIAL SET, 2 HOURS 20 MINUTES
AVERAGE RATE OF CONCRETING, 0·8 FEET PER HOUR
AVERAGE THEORETICAL SET LAG, 1·8 FEET
MAXIMUM HEAD OF WET CONCRETE, 4·5 FEET
TOTAL CONCRETE (GAUGINGS), 255 CUBIC YARDS

FIG. 54

RECORD OF CONTROL MEASUREMENTS TAKEN DURING CONCRETING OF A 60,000 KW. TURBO-ALTERNATOR PIER — STEAM END

LITTLEBROOK POWER STATION
KENT ELECTRIC POWER Co.
(BY COURTESY OF SIR ALEXANDER GIBB & PARTNERS).

The best method of providing for shrinkage in such structures as culverts is to leave a space between each concrete monolith which is to be concreted later. This space to be a minimum, which will allow of fixing and removal of shuttering to adjacent concrete blocks. (See Photograph No. 3.)

The lack of cracks in the 10-ft deep sealing slab of the Littlebrook pump house was no doubt due to such alternate pours, and the fact that a large number of " plums," in the shape of dense concrete pile heads, were used, which would tend to lower heat evolution.

Thick timber shuttering is to be preferred for use as shuttering as against steel, for such mass concrete works as turbo-alternator foundations where the conductivity affects the differential cooling of the concrete mass.

For building walls the specification should cover carefully the question of :—

(i) Rate of pouring and time interval between lifts.

(ii) The cleaning of " old faces " before new concrete is placed, as such junctions, if weak, may cause the start of deterioration. The application, after thoroughly wetting the old surface, of a concrete slurry somewhat richer in cement is to be preferred to the use of pure grout (55).

(iii) The control of construction joints. It would seem to be advisable to provide vertical construction joints at regular intervals in very long walls. These act as " contraction " joints and eliminate random cracks occurring.

(iv) The periods of curing.

As regards controlling the mix, the use of the central mixing plant has advantages only if large quantities are involved requiring practically continuous use, and if suitable transport is available. The incorporation of " full immersion " weighing apparatus, which weighs sand and aggregate constituents fully saturated with water, removes doubts about variations in proportions due to sand bulkage and gives a uniform water/cement content.

The control of construction joints in beams is equally important if cracks are to be avoided. These cracks form the basis of climatic deterioration, so often seen in long beams used under supports for switchgear in open air sub-stations. The best results would seem to have been obtained where these construction joints are situated at midspan of beams and girders.

Fig. 54 shows a typical running graph which was used to control the speed of concreting the turbo-alternator piers of Littlebrook Power Station. These piers were poured continuously, and apart from other considerations it was necessary to avoid excessive head of wet concrete bearing on the shuttering, and to allow for heat dissipation in the concrete.

Cost of excavation increases rapidly with depth, and rates are usually discontinuous at approximately 5-ft intervals. Timbering and bracing increase with depth. There may also be pumping charges to add to the rates where excavation is in water-bearing strata.

In connection with such bracings it is well to remember Tersaghi's theory of arch action (26). From his tests and studies of the problems he concludes that if a retaining sheet or wall deflects by " rotation " as shown in Fig. 55a, the strain in each horizontal element of material between the plane of rupture AC and the wall AB is constant, and in this case the total pressure and its distribution as determined by the Coulomb theory is substantially correct. But if the wall moves laterally as shown in Fig. 55b, the unit strain in each element is no longer a constant. There will be a tendency for the lower part of the wedge to subside owing to the excessive lateral yield of the wall in this region. The upper part of the wedge will then tend to drop vertically and cause arching action between the wall and the wedge. The net result will be a marked decrease in intensity of pressure at the base of the wall and a corresponding increase near the top.

In view of the heavy plant and other loads involved, it is important that piling and construction programmes should be so planned that the whole set of foundations forming a unit should be evenly loaded at all stages. It must be remembered that piles merely transmit surface pressures to a lower level, and if one particular region is loaded in excess of an adjoining region the lightly loaded sections will tend to rise—much in accordance with the bulging action previously noted for fills on marsh land. (Chapter III, Figs. 19 and 22.) This differential settlement is serious in cases where watertightness is desired and where expensive tiled finishes have been used on walls.

Similarly, the digging of trenches near to partially or wholly constructed foundations, columns, etc., is to be avoided unless thorough precautions have first been taken to avoid lateral movement of the latter due to soil failure or lateral deflection. A monthly check on bench marks on the site at Littlebrook Power Station revealed tendencies for buildings to " rise " due to adjacent loads, and trouble was experienced with columns moving owing to the presence of fairly deep trenches in the turbine house for the cooling water bus mains.

B. Buildings

Fig. 56 shows typical space requirements for a modern 120 mW station provided with basements.

The cost per cubic foot is found to vary widely with the building material used and the type of building. The popular practice for superstructures is either to use steel frame with brick walls, or steel framing with reinforced concrete walls, the walls, generally, not being load bearing. The main reason for this duplication is the time element. Thus it is possible to erect the steel columns and bracings and to place the roofs with pre-cast slabs in a comparatively short time, thereby affording sufficient weatherproofing to enable certain other plant or construction functions to proceed ; the walls being constructed later.

How widely the costs vary are shown in Table 17, which illustrates one case of brick walls, i.e. Battersea (15), and one of reinforced concrete construction, i.e. Littlebrook " A " Station.

It is logical to expect the unit prices of such structures as offices to be higher than those for less ornate structures such as boiler houses, owing to expensive wall and floor finishes, windows, doors and fittings. The unit prices for steel framing were not given in the case of Battersea.

The design of turbine and boiler house superstructures requires special attention from the point of view of :—

(i) Economic utilisation of space. Admittedly, in the turbine house ample space must be allowed for the withdrawal of machines and condenser tubes, and sufficient lifting height for the cranes, and space to allow for possible obsolescence risks. Even so there may be room for more economic use of space. A leaf might be taken from the book of Hydro-Electric Stations and cable and pipe culverts, pump bays and battery rooms, etc., so arranged that, within the framework of the above limitations available space is utilised to the highest degree.

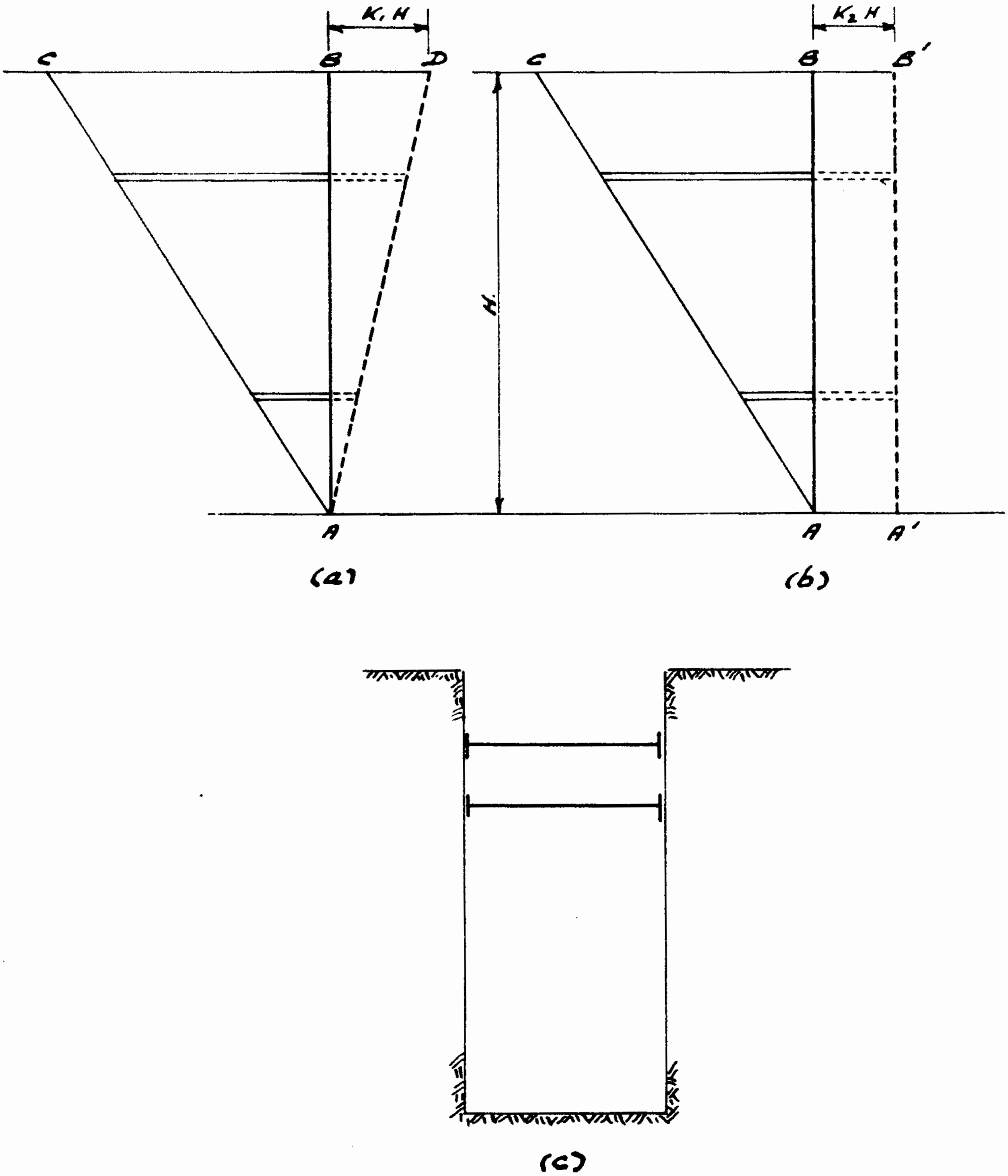


FIG. 55

TERSAGHI'S THEORY OF ARCH ACTION

FROM........(26)

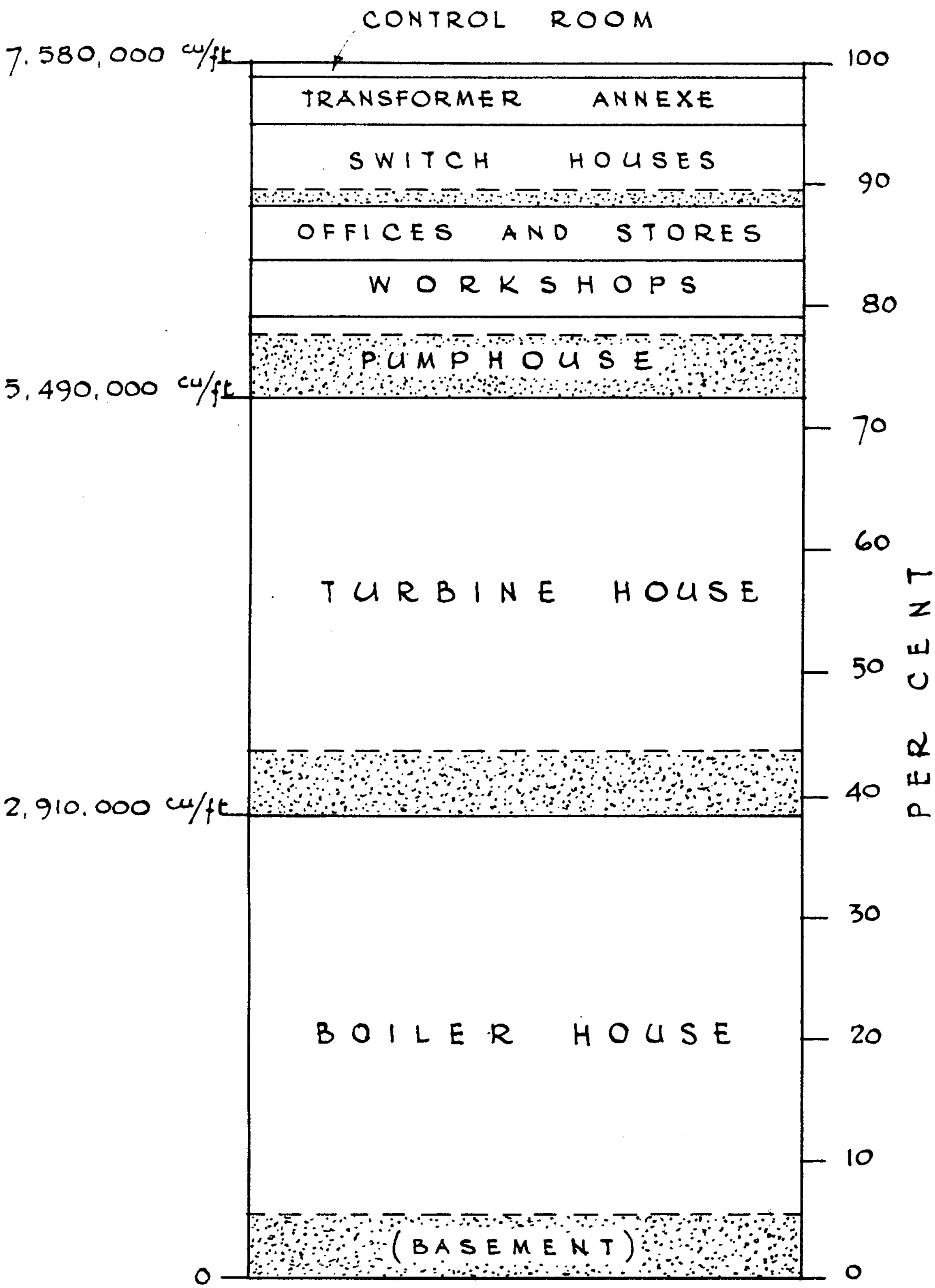


FIG. 56

TYPICAL SPACE REQUIREMENTS
120 Mw. STATION

TABLE 17

COSTS PER CUBIC FOOT OF TYPICAL SUPERSTRUCTURES

Building	Station	Superstructure Cost in Pence per Cubic Foot		
		Walls only	Framing only	Total
Boiler House	Battersea Littlebrook	— 2·88	— 5·76	10·29 8·64
Turbine House	Battersea Littlebrook	— 3·84	— 4·00	7·30 7·84
Switch Houses	Littlebrook	8·4	—	8·40
Switch Houses and Offices	Battersea	—	—	15·75
Offices and Stores	Littlebrook	13·44	4·00	17·44
Workshops	Littlebrook	5·47	4·44	9·91

(ii) Ventilation. These high buildings have a tendency to create a chimney effect, especially in view of the high inside temperatures, and if the ventilation systems of adjoining (smaller) buildings are not carefully designed their ventilators may be prone to act the reverse way, serving as an inlet for cold air which causes draughts and discomfort. In the boiler house such draughts may cause extensive damage to timber doors and frames through slamming.

(iii) Windows and lighting. Just before 1939 the designs for windows were carefully scrutinised from the point of view of air raid precautions. The experience of the war has shown that insurance in this direction may be outmoded very quickly owing to changes in explosives and tactics, and it becomes questionable whether reliance could be placed on such precautions. Post-war designs will probably concentrate on maximum lighting effect and external appearance. The use of large windows, operated in banks, is not advocated unless the promoter is prepared to bear the expense of robust reliable operating gear. All automatic operating gear should be capable of hand-operation, and this involves long rods and links, and unless these are robust, torque deflections cause erratic operation and much trouble and maintenance expense.

(iv) Condensation. The variable temperatures inside buildings make for frequent condensation troubles unless special attention is given to materials used and to the design of ventilation systems.

(v) Much time could be saved and a greater output per man-hour achieved by avoiding certain petty economies in the design of intermediate floors. The arrangement of beams often makes it possible for the designer to effect small economies by varying the thicknesses of slabs, say, from bay to bay, and by using reinforcing rods of different diameters. But the specialised shuttering required to effect this usually sends up the rates, and the time lost in checking, setting out, and supervision on site more often than not nullifies the savings expected by virtue of these " economies." The only justification for such fractional economy must be that overall (Master) economy is thereby effected.

C. General—Construction

Fig. 57 shows the progress record for the construction of Littlebrook Power Station and the man-hours and monthly certificates for the main civil engineering contractor. From this curve it was possible to prepare the " mass man-month " and " average cost per man-month " curves shown in Fig. 58.

From the latter it is seen that the cost per man-month tends to be high at the beginning of the contract, but tends to assume a constant value towards the end of the contract. This may be explained by the fact that at the beginning of the work certificates allow heavy sums on account of materials which are not yet fixed at a time when the labour curve has not yet risen to peak value. When working abroad contractors will be justified in asking for heavy " on account " payments for plant brought on site.

During the war " prefabrication " received much publicity, and some engineers would recommend a greater use of this type of construction in an effort to reduce the lags between rotation sequences of operations, e.g. navvies (excavation), carpenters, steelfixers, concretors and finishers.

Prefabrication is, however, not such a new conception. Bricks, piles, steel pipes, etc., are all examples of this type of work. War experience has shown that the greater application of this principle to reinforced concrete shows a total economy, i.e. time *and* cost, only if :—

(i) There is storage space in which to deploy the trades concerned all at the same time, and to store the products in the order in which they are required without untold double handling which, apart from cost and loss of time, involves risks of fracture and deformation.

(ii) The element of mass production exists. It is no earthly use prefabricating odd shapes and sizes all over a site with all attendant handling costs if the work could be equally well performed once and for all *in situ.*

(iii) If a great saving is shown in materials, such as shuttering, through re-use, which again implies (ii), or a gain in working space due to the consequent lack of struts, stays and clamps, etc., on the actual job.

(iv) If joining or jointing of individual units can be performed with the minimum of time lost and the maximum strength factor as regards functioning permanently (strength, watertightness, smoothness, etc.)

(v) If overlapping of trades, i.e. that " haggling " period, when, say, the last of the joiners are just leaving and the first of the steelfixers are trying to get in, is genuinely avoided.

Fig. 57 brings out clearly the jaggedness of the labour curve to be expected around holiday times, and full allowance must be made for this in fixing commissioning dates.

The peak in the labour curve (Fig. 57) comes well before commissioning date, at a time when a vertical line cuts the maximum number of " operations proceeding." The co-ordination required to keep the large number of men working at maximum efficiency is self-evident, and if loss of time is to be avoided, the necessity for having at all times reserve jobs ready to switch men on to, in view of demands imposed by co-ordination factors, weather, etc., is strongly emphasised.

The record (Fig. 57) is discontinued after December, 1940, but a considerable period is spent, at approximately constant labour, on finishes such as tiling, painting and making good ; which processes become islanded in the general concentration on essential work for an early date of commissioning.

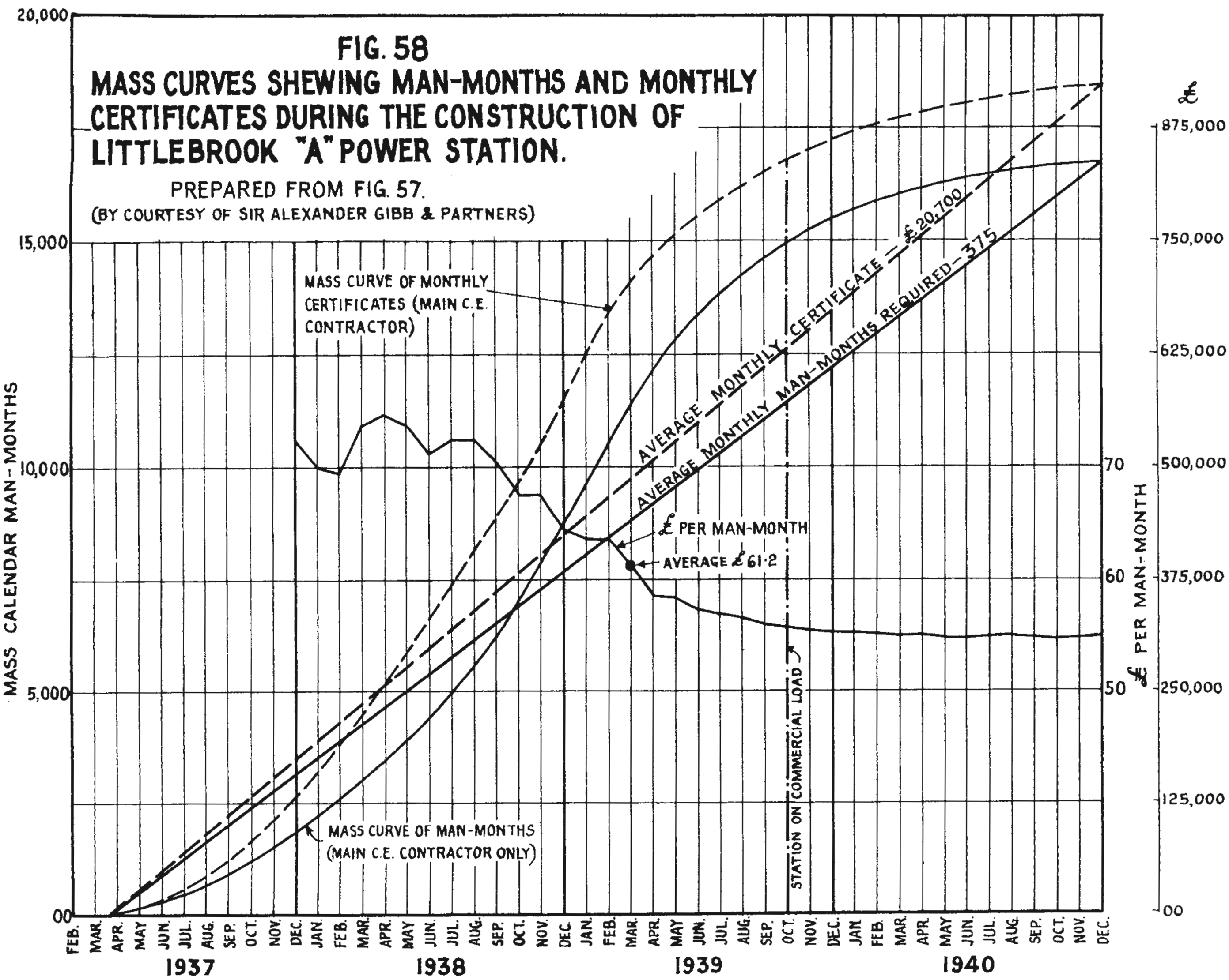


FIG. 58
MASS CURVES SHEWING MAN-MONTHS AND MONTHLY CERTIFICATES DURING THE CONSTRUCTION OF LITTLEBROOK "A" POWER STATION.
PREPARED FROM FIG. 57.
(BY COURTESY OF SIR ALEXANDER GIBB & PARTNERS)
MASS CURVE OF MONTHLY CERTIFICATES (MAIN C.E. CONTRACTOR)
AVERAGE MONTHLY CERTIFICATE – £20,700
AVERAGE MONTHLY MAN-MONTHS REQUIRED – 375
£ PER MAN-MONTH
AVERAGE £61·2
STATION ON COMMERCIAL LOAD
MASS CURVE OF MAN-MONTHS (MAIN C.E. CONTRACTOR ONLY)
MASS CALENDAR MAN-MONTHS
20,000
15,000
10,000
5,000
00
£ PER MAN-MONTH
70
60
50
MONTHLY CERTIFICATES
£
875,000
750,000
625,000
500,000
375,000
250,000
125,000
00
FEB. MAR. APR. MAY JUN. JUL. AUG. SEP. OCT. NOV. DEC.
1937
JAN. FEB. MAR. APR. MAY JUN. JUL. AUG. SEP. OCT. NOV. DEC.
1938
JAN. FEB. MAR. APR. MAY JUN. JUL. AUG. SEP. OCT. NOV. DEC.
1939
JAN FEB. MAR. APR. MAY JUN. JUL. AUG. SEP. OCT. NOV. DEC.
1940

On a power site, where access will always be at a premium, great attention must necessarily be given to plant layout for the contract, and any tendency to overplant must be curbed. Use should be made, as far as possible, of permanent plant, as for instance in the turbine house, where the main cranes if erected early in the contract could render valuable service in construction.

The tidiness of the site will almost invariably reflect the efficiency of the work. The contractors should have a plant superintendent on the site whose functions should be to expedite, clear hold-ups, maintain access, keep plant in good repair, and maintain a clean site, with no unnecessary double handling of dumped materials.

It is felt, therefore, that the outlook for steam generation will continue to be good for a long time to come, and that studies connected with the improvement of design and construction leading to greater economy will not be a waste of time.

A cursory glance at Figs. 1, 2 and 8 may lead one to the conclusion that saturation point had been reached as regards economic design. But these curves all reflect the trend of "Annual Operating Costs." The total costs curve is shown in Fig. 15, which shows the effects of the relative component curves—"Operating Costs" and "Fixed Charges"—in a typical case.

Any contributions which the civil engineer can make towards economy will be shown almost entirely in reduction of Fixed Charges, i.e. a clockwise rotation of this line (OZX in Fig. 15), and the effect on the Total Costs curve will be such as to increase the profits per pound invested and to increase the range for selection of the ideal investment point, i.e, flexibility of design.

Hence, even if, on the face of it, there would appear to be signs that the rate of increase in efficiency is decreasing, as revealed by the trend of Annual Operating Costs curves, the field is still wide open for lines of thought connected with the reduction of Annual Fixed Charges, i.e. for contributions from civil engineers.

When casting round for means of reducing capital costs, or Fixed Charges, one soon comes up against the following two main factors of influence :—

(A) Cost of money.

(B) Cost of labour and materials.

(A) Cost of Money

The basic rate of interest on capital has fallen steadily of recent years, and particularly in Great Britain, where the recent cheap money policy has brought a further drop in rates of interest. Whereas in Persia (Iran), for instance, it would be difficult to raise money for schemes of this nature at rates of interest below 10 per cent, and whereas the rates in the United States are given by Barrows as of the order of 6 to 7 per cent (61), and by Justin and Mervin (10) as 7 per cent, the British rates are of the order of $3\frac{1}{2}$ to $4\frac{1}{2}$ per cent.

The engineer has no control over interest rates, but he may be able to minimise the effects of the ruling interest rates on Fixed Charges by firstly reducing the actual capital costs on which interest is chargeable, and, secondly, by reducing contract times, i.e. the period during which interest is charged on capital expended before the effective earning date commences.

Using Fig. 58 we may work out a practical illustration of the effect on capital costs of reducing the contract time.

Assume that the money for each year's working is borrowed at the beginning of each year.

Then from the "Mass Curve of Monthly Certificates" the yearly borrowings for civil works become :—

Beginning 1937	£125,000
Beginning 1938	£575,000
Beginning 1939	£862,000

by which time the station comes on to commercial load.

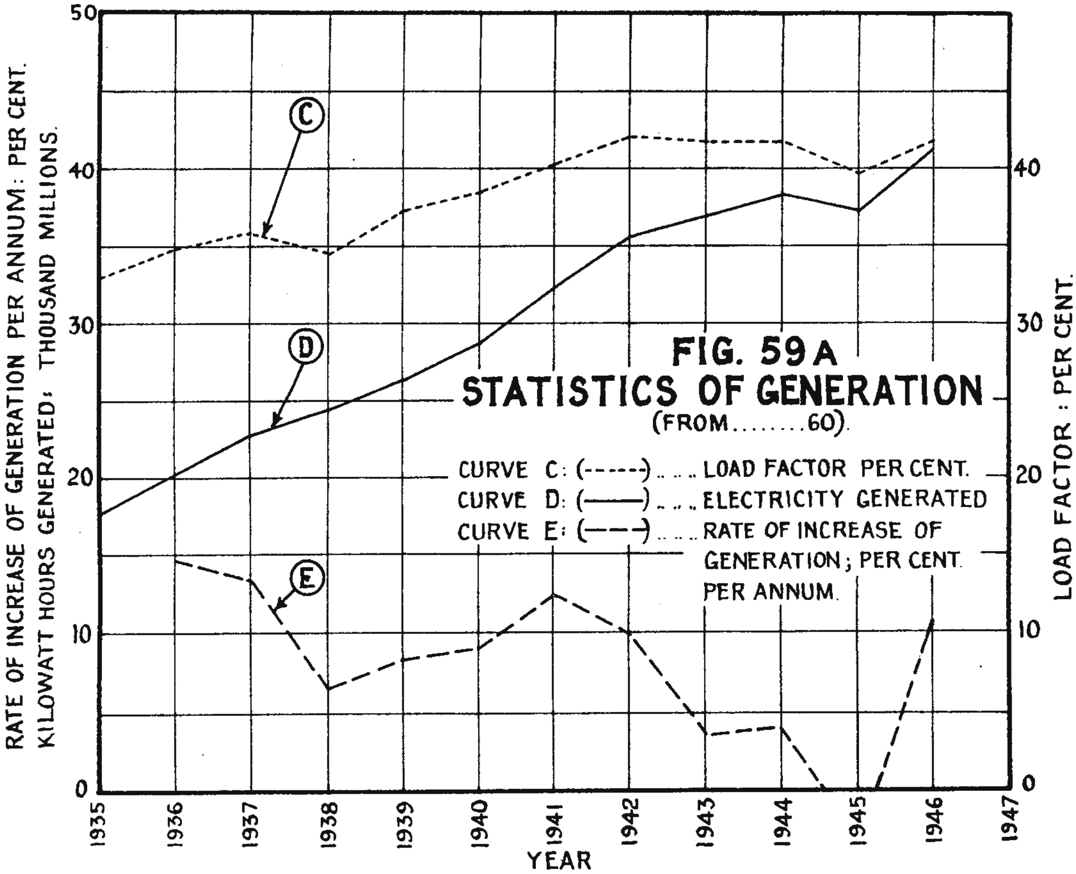


FIG. 59A
STATISTICS OF GENERATION
(FROM........60).
CURVE C: (------)......LOAD FACTOR PER CENT.
CURVE D: (——)......ELECTRICITY GENERATED
CURVE E: (– – –)......RATE OF INCREASE OF GENERATION; PER CENT PER ANNUM.
RATE OF INCREASE OF GENERATION PER ANNUM: PER CENT.
KILOWATT HOURS GENERATED: THOUSAND MILLIONS.
LOAD FACTOR : PER CENT.
YEAR
C
D
E

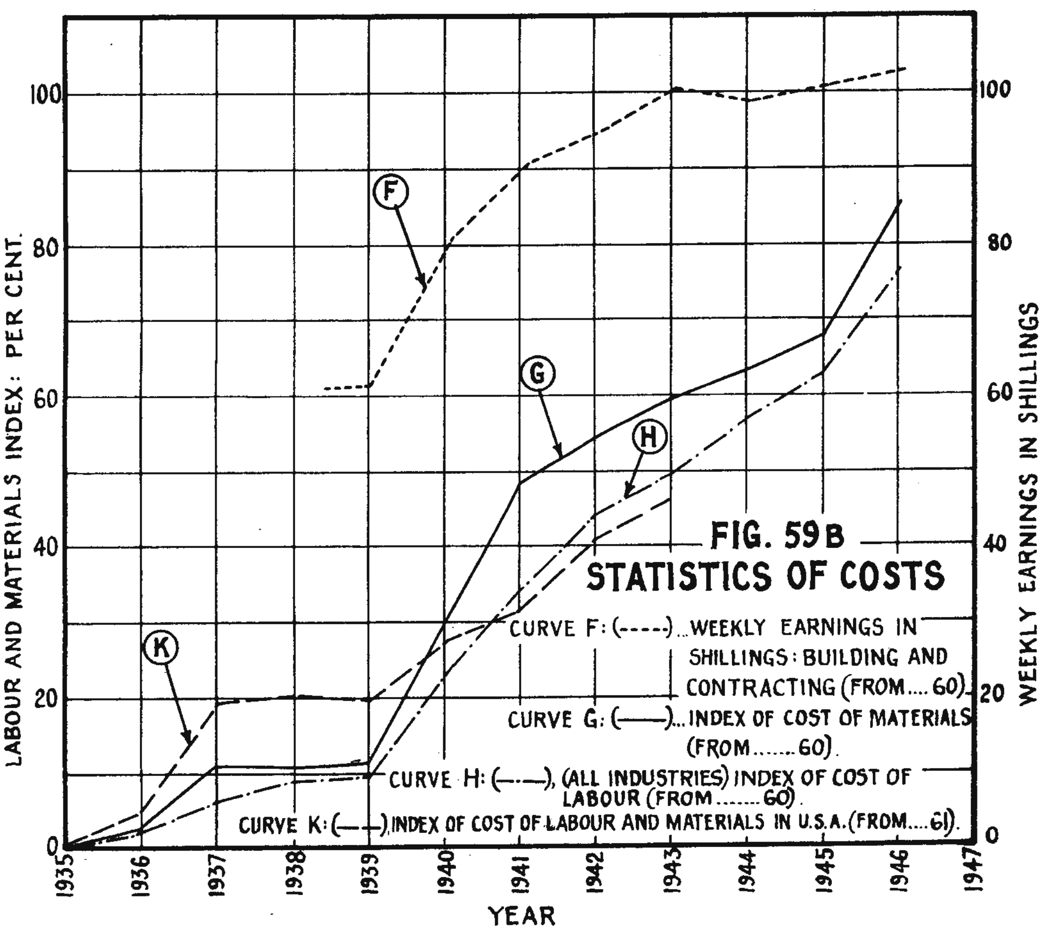


FIG. 59B
STATISTICS OF COSTS
CURVE F: (-----)...WEEKLY EARNINGS IN SHILLINGS: BUILDING AND CONTRACTING (FROM.... 60).
CURVE G: (——)...INDEX OF COST OF MATERIALS (FROM.......60).
CURVE H: (—·—), (ALL INDUSTRIES) INDEX OF COST OF LABOUR (FROM.......60).
CURVE K: (– – –), INDEX OF COST OF LABOUR AND MATERIALS IN U.S.A. (FROM....61).
LABOUR AND MATERIALS INDEX: PER CENT.
WEEKLY EARNINGS IN SHILLINGS
YEAR
F
G
H
K

Allowing an interest rate of 4 per cent, the total capital borrowed at the end of 1939 works out at..£920,608

Net works capital £862,000

And interest during construction £58,608

Or....6·8 per cent

Assume that this work has been executed over a period of five years, the same net works capital being involved. Over such a period it could be taken that the " mass curve of Monthly Certificates " would be practically " straight" i.e. the annual borrowings would tend to be more equal. Under these assumptions :—

The total capital borrowed becomes (at 4 per cent) £926,051

Net works capital as before £862,000

Interest during construction £64,051

Or ....7·4 per cent

At first sight one is tempted to conclude that very little difference is made to capital cost by reducing the period of construction, since :

For 5 years .... Ratio : Total capital/Net capital = 1·074

For 3 years .... Ratio : Total capital/Net capital = 1·068

But before drawing such conclusions the following must be considered :—

(i) The variation of cost of materials and labour over such delay periods.
Fig. 59B, Curves F, G and H show the variations of costs and index figures for labour and materials in Great Britain during the period 1935-46. Curve K shows similar index figures for the U.S.A.
From the labour index Curve H we derive that the average rate of increase of cost over this period amounted to 5·36 per cent per annum !

(ii) The effects of retarding the earning date of the station.
Any advance in the earning date means a greater insurance against obsolescence risks. Since a station has a given time for operating at high efficiency before it begins to slide down the scale and become superseded by newer and more efficient stations (in a grid system), it is obvious that any gains in time to commence operating, and so to commence " paying off," mean a cash saving in the avoidance of financial insurance against functional depreciation.

One further example may be helpful. Using Fig. 58 as being a practical case (Littlebrook Power Station), it is noted that the greatest rate of certificate expenditure occurs over the period October, 1938-February, 1939, for which period the daily rate is £1,666 per day !

From Fig. 57 the labour force during December, 1938, was just over 900. From Fig. 59B, Curve F, the average weekly earnings at the time was 61 shillings.

Assume that for some reason a delay or hold-up occurs at this " highly organised " stage, causing an effective loss, i.e. a delay in commissioning of two months.

Borrowing for 1938 was £575,000 (Fig. 58).

Interest on dormant borrowings :—

$$£575{,}000 \times \frac{4}{6 \times 100} \quad \ldots\ldots\ldots\ldots \quad = \quad £3{,}833 \quad (a)$$

Capital " lost " on dormant labour :—

$$£9 \text{ weeks} \times \frac{61}{20} \times 900 \quad \ldots\ldots\ldots\ldots \quad = \quad £24{,}705 \quad (b)$$

Total certificate expenditure indicated as that which would have occurred if there had been no delay :

£1,666 × 60	£99,960		
of which labour accounted for	24,705		
Hence materials accounted for	£75,255		
A claim for dormant materials for two months at 4 per cent amounts to		=	£502 (*c*)

There is no recognised manner of allowing for increased risk of obsolescence owing to such a delay, and the matter must be approached from first principles. Assume that the capital would normally have been paid off in 20 years. If now a delay of two months occurs before earning commenced it can be argued that, if obsolescence risks are not to be increased, then the plant must amortise by the same time, i.e. in 19·83 years, as compared with the 20 years previously allowed for.

We have seen previously, for the practical case worked out from Fig. 58, that the total capital allowing for interest during construction, worked out at 1·068 of the net works capital, i.e. £920,608.

Annual payments for 20 years period = £46,030.

Annual payments for 19·83 years period = £46,425. (without allowing for corrections (*a*), (*b*) and (*c*) above. Assume straight line method of payment).

Difference in annual amortisation payments....£395.

Capital value which at 4 per cent would require an annual payment of £395 is...... £9,875.

Hence suggested value to insert as allowance against increased risk of obsolescence .... = £9,875

TOTAL EXTRA COST £38,915

This amounts to 4·25 per cent of total Scheduled Capital Cost (£920,608).

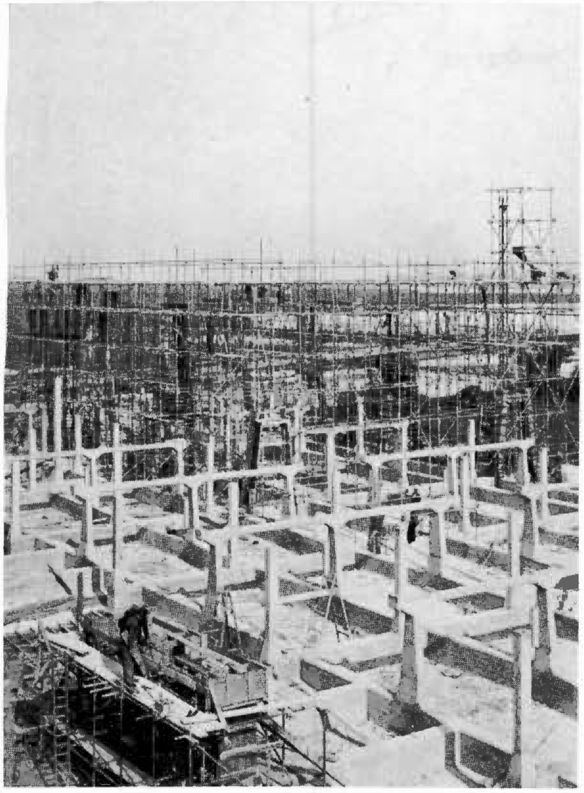
(B) Cost of Labour and Materials

The next consideration is that of labour and materials. It is a risky affair to try and predict the trend of costs after the post-war unsettlement has died down.

The curves shown in Fig. 59B show the trends over the period 1935-46.

The following are interesting features of these curves :—

(1) From Curve F we note that the average weekly earnings in Contracting and Building, after the steep rise of the period 1939-43, seem to have increased at a much slower rate. Yet the Labour Index for all industries (Curve H) seems to be rising still. It would not be wise therefore to deduce that the rise in labour costs has been arrested.



Photograph No. 5

Outdoor 132 kV Switch Station, Littlebrook Power Station, showing layout of reinforced concrete supports and beams for switchgear plant.
Note scaffolding in background for concreting " A " frames and " H " beams.
See Photograph No. 6.

Photograph No. 6

Outdoor 132 kV Switch Station, Littlebrook Power Station, Showing close-up view of reinforced concrete " A " frames and " H " beams.
See also Photograph No. 5.

Assume a datum concrete stress of 750 lb per sq. in., and that for the calculations below the steel stress is kept constant throughout at 18,000 lb per sq. in.

For any variation of concrete stress from datum stress two major changes take place affecting costs :—

(i) There is a change in the relative quantities of ingredients per unit of finished concrete.

(ii) There is a change in finished slab or beam thickness, i.e. a change in absolute concrete quantity, and hence of ingredients.

Changes in the relative quantities of ingredients (i) are shown in Table 18 below, which is based on the Code of Practice figures for ballast aggregates (57) :—

TABLE 18

RELATIVE QUANTITIES OF CEMENT AND AGGREGATE IN 5·75 CU. FT. OF FINISHED CONCRETE FOR DIFFERENT MAXIMUM CONCRETE STRESS SPECIFICATIONS

Concrete Stress lb/sq. in.	Cement cwt	Aggregate cu. ft.
750	1·000	7·50
850	1·278	7·17
925	1·534	6·90
975	1·785	6·76

Variations in concrete slab or beam thicknesses (ii) due to varying stress specification are controlled by the formula :—

$$t^2 = \frac{M}{Rb.}$$

Where t = Concrete thickness.

M = Bending moment.

R = Modular ratio (controlled by stress specifications for concrete and steel).

b = Breadth of beam or slab.

Note : Modular ratios used are from the Code of Practice (57).

With a constant bending moment and a given width of beam or slab, the thickness is therefore proportional to :—

$$\frac{1}{R^{0\cdot5}}$$

Owing to this reduction in thickness of concrete there is an increase in the economic percentage of steel with increase of concrete specified stress.

The quantities of ingredients shown in Table 18 can now be corrected for the concrete savings accruing from " t " variations, as shown in Table 19.

Table 20 gives these corrected figures, as also the steel figures corresponding to the various stresses.

Table 19 gives the relevant corrections to make for the various stresses.

TABLE 19

PERCENTAGE SAVING IN CONCRETE WITH INCREASE OF STRESS SPECIFICATION

Concrete Stress lb/sq. in.	$R^{0.5}$	$t = \frac{1}{R^{0.5}}$	Per cent Saving in Concrete
750	11·69	0·0856	—
850	12·45	0·0804	6·07
925	13·00	0·0769	10·15
975	13·33	0·0750	12·39

A set of Cost Curves, in pence, can now be prepared, giving the variations in cost of individual ingredients (cement, aggregate and steel) of 5·75 cu. ft. of finished concrete, and so of the total cost of the concrete for an increase in concrete stress specification, above the datum stress of 750 lb per sq. in., and using different prices for the different ingredients.

Such curves are shown in Fig. 60, based on the following assumed prices :—

Cement
- (*a*) 3s. per cwt (Typical U.K.).
- (*b*) 6s. per cwt (Possible abroad).

Aggregate
- (*a*) 10s. per cu. yd. (U.K. or abroad).
- (*b*) 20s. per cu. yd. (U.K. or abroad).

Steel
- (*a*) 20s. per cwt (Typical U.K.).
- (*b*) 40s. per cwt (Possible abroad).

From Fig. 60A we see how very influential is the cost of cement in the pure concrete characteristics (i.e. excluding steel)—see the difference between Curves C and D. Curves A and B show the steel characteristics. Fig. E is a combined characteristic for prices such as might apply to Great Britain.

In view of the great difference between Curves C and D, it is interesting to note the characteristics F and G plotted in Fig. 60B, using prices of ingredients such as might apply in the U.K. and abroad. Curve F represents U.K. conditions, and Curve G represents conditions such as might apply abroad, both curves plotted on a percentage basis.

At 900 lb per sq. in. the increased cost in the U.K. (F) would be 4 per cent, but abroad would be 12·7 per cent (G)—a difference of 8·7 per cent, or 18·5 pence per 5·75 cu. ft. or 3·2 pence per cu. ft.

Now, it is possible that the saving in shuttering, weight, centering and foundations, due to the reduction in thickness of concrete may outweigh the U.K. 4 per cent (though it must be remembered that for an increased stress specification greater supervision is necessary), but it is doubtful whether such savings would always outweigh the 12·7 per cent abroad.

TABLE 20

SHOWING RELATIVE QUANTITIES OF INGREDIENTS IN 5·75 CU. FT. OF CONCRETE (AFTER CORRECTIONS HAVE BEEN MADE FOR VARIATIONS IN THICKNESS) FOR VARIOUS CONCRETE STRESS SPECIFICATIONS

Concrete Stress lb/sq. in.	Corrected Cement Quantities cwt	Corrected Aggregate Quantities cu. ft.	P = Economic Percentage Steel	Steel Area : Proportional to t × p	Increase in Steel Per cent*
750	1·000	7·50	0·887	0·0760	—
850	1·201	6·74	1·005	0·0808	6·3
925	1·378	6·20	1·093	0·0840	10·5
975	1·564	5·92	1·153	0·0865	13·8

* Steel required at 750 lb/sq. in. for 5·75 cu. ft. of concrete = 25 lb.

The moral is : when choosing a design stress it will be well to bear in mind the relative costs of the ingredients. Or, when applying old formulæ, it may be well to check what relative alterations in prices have taken place in the intervening period. It is particularly important when designing structures for countries where import prices have to be paid for cement and steel to bear in mind these characteristics.

Whilst on the subject of concrete stress it might be pertinent to point out that it is not sufficient to nominate a desirable stress without ensuring that the specification provides sufficient incentive to the " manufacturer " of concrete (the contractor) to guarantee that the proper methods shall be used in the production of concrete which will ensure that the paper economies are translated into facts. One of the most obvious improvements required in the manufacture of concrete is the elimination of the effects due to the variation of water content in the sand.

Since the strength and behaviour of concrete is so dependent on water/cement ratio, it follows that if speedy and effective methods of control are established which ensure a constant water content, then cement savings become possible because it will no longer be necessary to over-specify cement in order to make sure that the whole range of possible water contents is covered.

Planning

The preceding chapters have attempted to deal with the broad routes to economy.

It is of interest to note that physicists and philosophers have their own name for the Straight Line Energy Theorem referred to in this work—the " Simplicity Postulate." Sir James Jeans in " Physics and Philosophy " (62) explains how, since efforts to discover the true nature of reality have failed, we must utilise new philosophical principles, of which so far we have not made any use. One of these is the Simplicity Postulate, which asserts that : " Of two alternatives, the simpler is likely to be nearer the truth." He quotes Einstein as having remarked that " in every important advance the physicist finds that the fundamental laws are simplified more and more as experimental science advances."

There is then no need to be ashamed of our own simplicity (straight) theory !

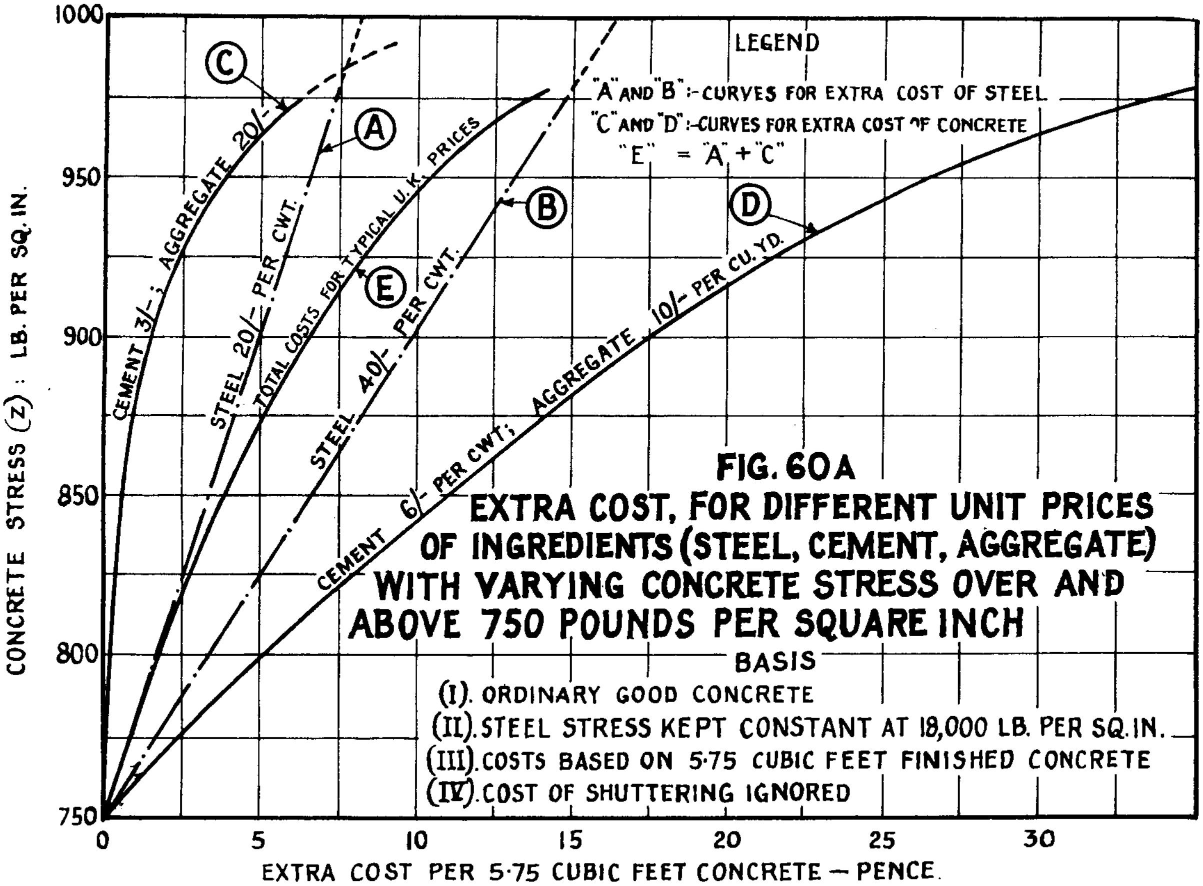


FIG. 60A

EXTRA COST, FOR DIFFERENT UNIT PRICES OF INGREDIENTS (STEEL, CEMENT, AGGREGATE) WITH VARYING CONCRETE STRESS OVER AND ABOVE 750 POUNDS PER SQUARE INCH

BASIS

(I). ORDINARY GOOD CONCRETE

(II). STEEL STRESS KEPT CONSTANT AT 18,000 LB. PER SQ. IN.

(III). COSTS BASED ON 5·75 CUBIC FEET FINISHED CONCRETE

(IV). COST OF SHUTTERING IGNORED

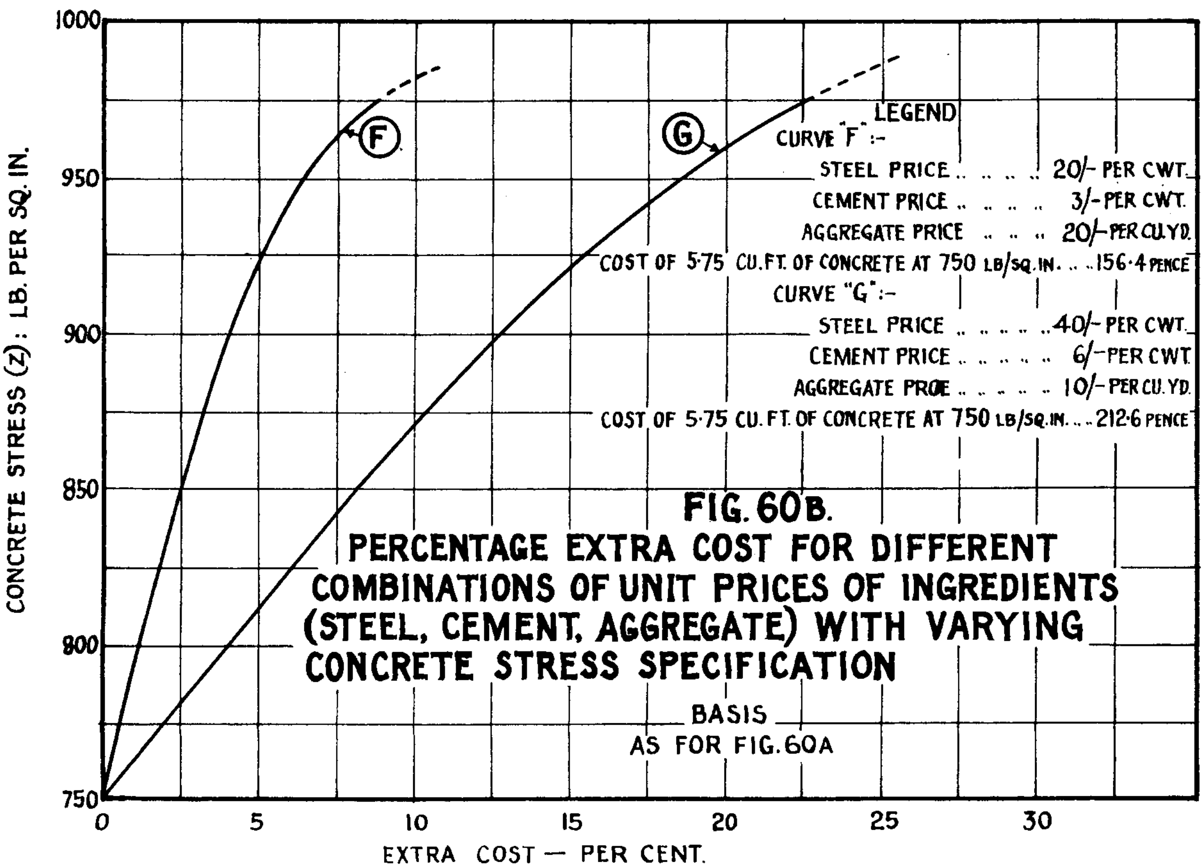


FIG. 60B.

PERCENTAGE EXTRA COST FOR DIFFERENT COMBINATIONS OF UNIT PRICES OF INGREDIENTS (STEEL, CEMENT, AGGREGATE) WITH VARYING CONCRETE STRESS SPECIFICATION

BASIS

AS FOR FIG. 60A

Another point to remember in planning and co-ordination is the Time Element. A healthy respect for this dimension will prove to be a great help towards economy.

A reduction in reserve and savings through avoided investment is another method of effecting economy.

Fig. 3 shows how power engineers have laboured in the past to reduce reserve capacity, and with what success. An investigation as to why there has been deviation from the principles of the Straight Line Energy Theorem almost invariably leads to the conclusion that sacrifices have been made on the altar of " Continuity of Service," which demand adequate safeguards against hold-ups due to strikes, failures of service, etc.

Chapter V, dealing with the Fuel Circuit, demonstrates how this circuit, in the case of coal firing, is loaded with capital spent on reserve. Here there exists the greatest opportunity of Avoided Investment, and hence for simpler or more tidy design.

A brief example may help in assessing the order of such reserve capital " lost." Assume a station fed by sea (river) borne coal. In the interests of continuity of service it has been the practice to provide :—

(i) Alternative road/rail coal access with tippler plant.

(ii) A large coal store involving capital sunk in :

- (*a*) Cost of extra land required.
- (*b*) Capital represented by coal lying dormant in the coal store.
- (*c*) Cost of coal lost through deterioration and spontaneous combustion.
- (*d*) Cost of extra reclaiming gear and foundations.
- (*e*) Cost of lengthening other circuits, such as the cooling water circuit, in cases where it is intended to avoid extra weight over the culverts, and where the best site layout would normally have demanded a route passing under the coal store.

(iii) Gravity bunker storage in the boiler house. (See typical capacities shown in Table 15.)

Considering Item (i). The cost of one tippler pit as additional safeguard would, at Battersea prices (15), amount to, say, £8,800. Allowing for modifications to railway access, and extra conveying plant, a further £6,000, the costs under Item (i) may be estimated as of the order of	£15,000
Consider Item (ii) above. It was seen from Chapter V that a 300 mW station, operating at 60 per cent plant factor and 1·2 lb of coal per kWh, with one month's reserve storage required space to store 70,500 tons of coal. Assuming a limiting storage height of 20 ft, and 79 lb per cu. ft. (average), this means an area of 2·3 acres, say 500 by 200 ft. Assume a cost of land for river frontage of only £10,000 per acre, then Item (ii) (*a*) becomes	£23,000
Allow for only 50 per cent of the total capacity of the coal store being fully dormant throughout the year, and taking coal cost at 20s. 3d. per ton, which was the average cost in 1938 (3), the capital sunk in coal lying dormant amounts to (ii) (*b*)	£35,700
Taking an annual loss through deterioration and combustion as half per cent of capacity, the annual cost for coal lost works out at £358, which, at 5½ per cent rates, justifies a capital cost of (ii) (*c*)	£6,500
Allowing for 500 ft of double bridge track piled foundations in reinforced concrete, complete with rails and stops, at £16 per ft run, and allowing for a coaling bridge to span 200 ft, and for reclaiming cranes, extra conveyors, etc., a sum of £34,000, the costs for handling reserve store coal amounts to (ii) (*d*).....	£42,000
Ignoring the cost of probable lengthening of other circuits (Item (ii) (*e*)) Total costs	£107,200

It is difficult to make a general estimate for the items under Item (iii). Bunker capacity may vary as follows (Table 15) :—

Battersea S.F. .... 6,300 tons for 4-312,000 lb/hr boilers.

Dunstan " B " (P.F.) .... 2,400 tons for 8-156,000 lb/hr boilers.

Probably the best method of making a general estimate of the costs of such reserve is on a basis of cost of building space—including for steelwork. Based on Littlebrook " A " practice and prices (see Table 17), the cost allowance for such a 300 mW station amounts to about £68,500. (On this basis the bunkers are included in the steelwork, and the space-cost allowance caters for a share of the supporting steelwork. The overhead charging plant is omitted, since the nature of such installations depends very much on site conditions. The estimate ought therefore to be conservative.)

Total estimate of reserve costs (Items (i), (ii) and (iii)) therefore amounts to £190,500.

On the basis of, say, £20 per kW installed, a 300 mW station costs £6,000,000, and the cost of coal reserve therefore amounts to 3·18 per cent of total station costs !

Referring to Table 4, we note that the cost of all fuel handling, storage, etc., exclusive of land, for an actual installation, amounted to as much as 17·96 per cent of total station cost.

If the civil engineering costs of the above 300 mW station were taken at 37·5 per cent of total cost, then the cost of such reserve amounts to 8·5 per cent of the civil engineering costs.

It seems clear that with so high a percentage of the total civil engineering costs devoted to the establishment of reserve, it should not be a wasteful occupation to devote attention to the problems of reducing this reserve and so achieving economies and, incidentally, streamlining the station by achieving cleaner lines, through straightening the flow circuits.

But the initiative in this respect must come from the mechanical engineers, since this is largely their circuit.

One way of straightening this circuit is to design for pulverised fuel only. Thus the overhead bunker storage could disappear and, if not altogether, then it would at least be possible to design low level outside bunkers, which are not so expensive in building space, and which do not add so much load to the main foundations. From there the coal could be fed direct to the crushers and mills, and so to the boilers.

We have seen in Chapter V (B) that oil fuel, where considerations of price and strategy do not affect the issue, is the best medium for simple flow lines, owing to its superior " mobility."

The whole question of how much reserve storage to allow for each large station connected to a grid system really means a careful and scientific assessment of " risks " to be borne per station.

Multiplicity of Function

Another form of avoided investment is by deliberately letting one installation perform more than one function. Another way of stating this would be to say that the " load factor " of structures has to be improved. To quote simple examples : a stanchion supports the weight of boilers, bunkers and roof—but its hollow space may also be used to good advantage by housing small sized pipe runs, provided the layout is such that full inspection and painting is possible without interfering with the operation of the station. The piles driven to support cooling water culverts may also be made to carry light incremental loads from coal conveyor trestle or of pipe trenches, etc. A bent of two piles would certainly not be fully loaded to capacity when supporting a conveyor trestle, and the foundation capacity would therefore be wasted. But the incremental loads imposed by adding the conveyor loads to those already imposed by the other structures, such as in the above example, would not mean much reorganisation in design.

These simple examples are not quoted in the absolute. That is, there is no suggestion whatever that cooling water culverts must carry conveyor trestles, and hollow stanchions must carry pipe runs ! It means only that the designer must be on the alert to seize such opportunities should site conditions and layout permit, and so avoid investment on parallel sets of foundations, each not fully loaded, when, by slight rearrangement of layout, a higher efficiency could be obtained with one set.

The greatest opportunity for economy, in so far as civil engineers are concerned, undoubtedly lies in the field of materials and the use of new materials.

This leads on to the subject of research. Engineers sometimes tend to fight shy of research and to regard it as an occupation remote from their day-to-day experience of construction. Yet the engineer's laboratory is on the site. It is there that he must note the shortcomings and inefficiencies of plant for the manufacture or placing of existing materials and work out modifications and improvements. It is there that he must observe the characteristics and performance of all materials. I venture to go further, and to say that it is from the site that the demand for new materials must come. The engineer could specify the characteristics of new materials he would like to use, and thus set the research worker his task.

In any case there are grades of research. There is the pure research work of a physical or chemical nature, which sets itself the task of discovering new phenomena, and studies the behaviour of matter. An example is atomic research. But other organisations are busy with work more directly concerning the engineer. The Building Research Station of Great Britain, and its various branches, are doing the most valuable work in connection with the use of construction materials. The practising engineer must work more closely with these organisations, and must give them practical reports on the behaviour under different conditions of the various plant and materials on the sites, and must ask them to investigate and solve problems which arise on the sites. It means exchanging information and making construction sites more " open " to these investigators.

The following is but a brief list, as an example of some of the problems which arise in connection with thermal stations, and which require looking into from the point of view of the civil engineer :—

(1) In ash disposal by hydraulic means there is the question of finding a method of reducing the expensive wear of abrasive ashes on pipes. Thick cast iron pipes are used, but even here the wear is such that pipes have to receive a quarter turn at frequent intervals throughout the year. Special bends have to be designed which also require frequent replacement. The process is expensive, both in capital cost and in operating, since trenches have to be continually opened and made good, and in some cases power output may be reduced for periods during which a pipeline is out of action.
Could not research find a lining to pipes which would obviate these difficulties and costs ? It must be tried, and the matter should not be left solely to the supply companies.

(2) It is a well-known fact that soils may contain compounds which are harmful to pipes carrying water or air, and particularly when there are ashes in the vicinity.
But the very short length of life of some of the mains laid at one modern power station, and the nature of the " wear " which occurred, made the author suspect that there may be agencies active other than mere chemical corrosion. Would it be possible for electrolytic action to take place ? Can it be that stray earth currents are caused whenever switching takes place—particularly in a site with a high water table—and do these earth currents find their way to the metal mains and cause electrolytic corrosion ? Experimental research is necessary and a way must be found to measure whether such currents are present and, if so, how to insulate the mains against them.

(3) More work is necessary to find out how conduits do behave under various fill pressures. We have seen in Chapter IV that, although some experimenters have explored the fringes of this problem, the findings up to date have not been sufficiently reliable for use in engineering design. Too much interpretation or guessing is still necessary, and the practical experiments described in Chapter IV have shown that, in addition to fill pressures there may also be short-term negative water pressure in the outlet culverts owing to sudden opening and closing of condenser valves, or due to stopping and starting of pumps.

4) The problem of water-proofing concrete structures without using undue thicknesses of walls requires study. Much of the space which is often wasted at present could then be used for the housing or storage of electrical equipment which has to be kept free from damp.

(5) Much research work is necessary to find and develop new building materials. We must aim at lighter materials which can be handled easily, have great durability, and which provide the minimum of dead load on foundations.
It may even be possible to find a use for a station by-product such as ashes, which, under present conditions, is a burden, not an asset.

(6) Constant review of statistics is necessary to keep up to date with the movements of prices, whether of money, labour or of materials. All these affect civil engineering works, and statistics do show the trend of things to come. In countries such as Britain and the United States of America reliable statistics are kept which need only be studied. In some countries, especially the younger ones, this has not yet been possible, or statistics have been kept for only a short time, or they are unreliable. The engineer requires that such statistical data affecting his work is kept and published, so as to be readily available.

It is interesting to note that in thermal power engineering the foundations have a life of 75 years or more, but the plant have a life ranging from 10 to 20 years. This means a different rate of depreciation for foundations as compared with the plant it supports. In fact, foundations could support two or three generations of plant.

Future tendencies might therefore well be to design very light superstructures which could almost be changed with the plant as new designs come along. If through research work strong but light materials are discovered, this practice could be followed. The advantages would be a low initial capital investment in superstructures, less risk of obsolescence, utilising the low depreciation rate of the more durable foundations and, finally, from the point of view of national security, it would mean that the plant and upper structures could be moved easily or, alternatively, suitable precautions could be taken at the time of the threat, in the light of prevailing circumstances rather than incurring from the start heavy annual charges resulting from conjectural " insurance " investment in special structures which may be obsolete a few years from the date of installation.

It may be fitting to end these notes in a similar vein to that of the opening paragraphs in the Introduction. In view of the many diverse problems and the number of branches of engineering associated with this type of work it follows that such sites are excellent schools for young engineers in which to learn their profession. This holds even if they do not necessarily wish to follow a career devoted only to power engineering. The educational facilities offered by such sites may be another factor to be reckoned with when considering guarantees for continued improvements in design and construction methods.

THE END

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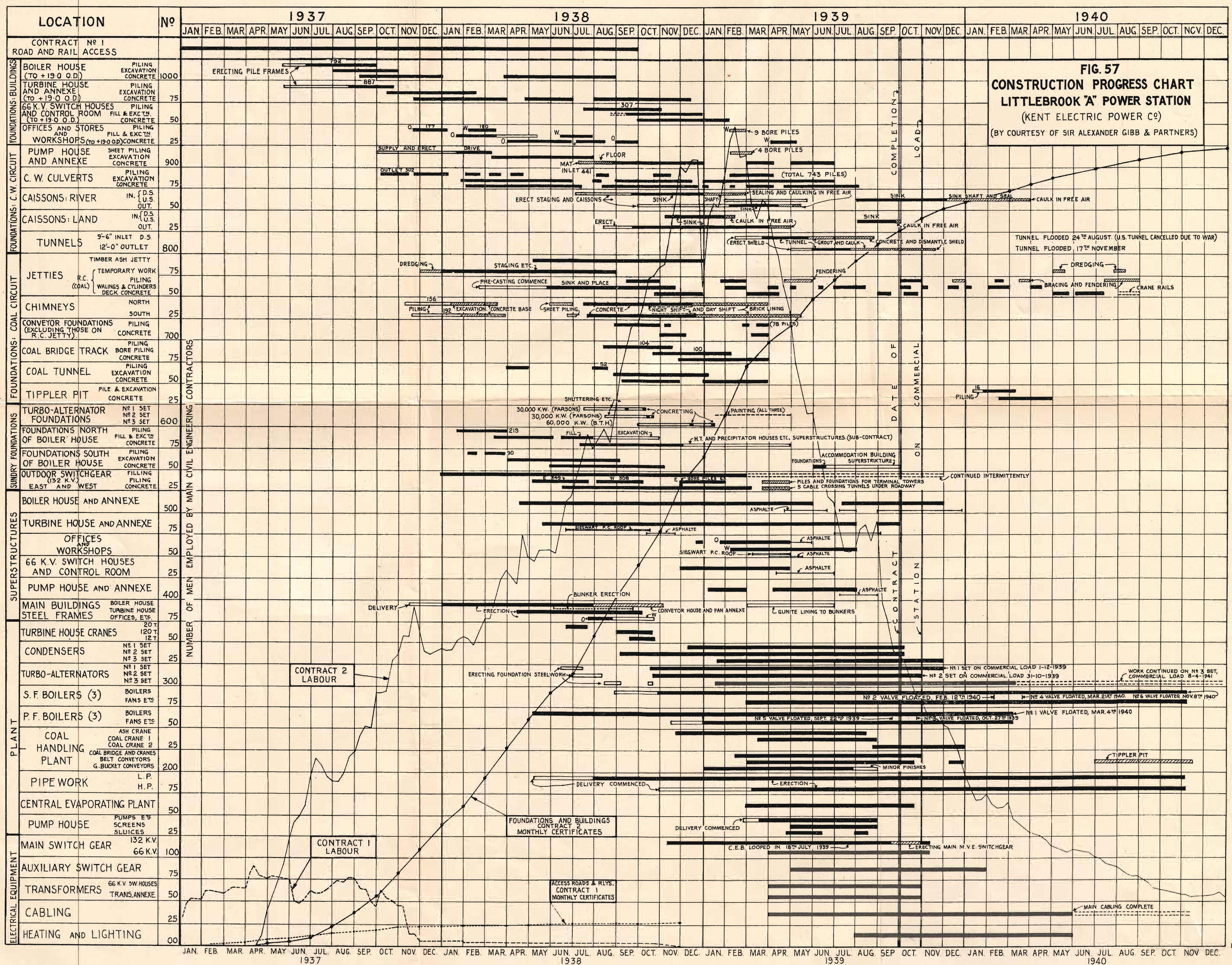
FIG. 57
CONSTRUCTION PROGRESS CHART
LITTLEBROOK "A" POWER STATION
(KENT ELECTRIC POWER Co)
(BY COURTESY OF SIR ALEXANDER GIBB & PARTNERS)
LOCATION
№
1937
1938
1939
1940
JAN. FEB. MAR. APR. MAY JUN. JUL. AUG. SEP. OCT. NOV. DEC.
CONTRACT № 1 ROAD AND RAIL ACCESS
FOUNDATIONS: BUILDINGS
BOILER HOUSE (TO + 19·0 O.D.) PILING EXCAVATION CONCRETE
TURBINE HOUSE AND ANNEXE (TO + 19·0 O.D.) PILING EXCAVATION CONCRETE
66 K.V. SWITCH HOUSES AND CONTROL ROOM (TO + 19·0 O.D.) PILING FILL & EXCTN. CONCRETE
OFFICES AND STORES AND WORKSHOPS (TO + 19·0 O.D.) PILING FILL & EXCTN. CONCRETE
FOUNDATIONS: C.W. CIRCUIT
PUMP HOUSE AND ANNEXE SHEET PILING EXCAVATION CONCRETE
C. W. CULVERTS PILING EXCAVATION CONCRETE
CAISSONS: RIVER IN. D.S. U.S. OUT.
CAISSONS: LAND IN. D.S. U.S. OUT.
TUNNELS 9'-6" INLET D.S. 12'-0" OUTLET
FOUNDATIONS: COAL CIRCUIT
JETTIES TIMBER ASH JETTY R.C. (COAL) TEMPORARY WORK PILING WALINGS & CYLINDERS DECK CONCRETE
CHIMNEYS NORTH SOUTH
CONVEYOR FOUNDATIONS (EXCLUDING THOSE ON R.C. JETTY) PILING CONCRETE
COAL BRIDGE TRACK PILING BORE PILING CONCRETE
COAL TUNNEL PILING EXCAVATION CONCRETE
TIPPLER PIT PILE & EXCAVATION CONCRETE
SUNDRY FOUNDATIONS
TURBO-ALTERNATOR FOUNDATIONS № 1 SET № 2 SET № 3 SET
FOUNDATIONS NORTH OF BOILER HOUSE PILING FILL & EXCTN. CONCRETE
FOUNDATIONS SOUTH OF BOILER HOUSE PILING EXCAVATION CONCRETE
OUTDOOR SWITCHGEAR (132 K.V.) EAST AND WEST FILLING PILING CONCRETE
SUPERSTRUCTURES
BOILER HOUSE AND ANNEXE
TURBINE HOUSE AND ANNEXE
OFFICES AND WORKSHOPS
66 K.V. SWITCH HOUSES AND CONTROL ROOM
PUMP HOUSE AND ANNEXE
MAIN BUILDINGS STEEL FRAMES BOILER HOUSE TURBINE HOUSE OFFICES, ETC.
PLANT
TURBINE HOUSE CRANES 20 T. 120 T. 12 T.
CONDENSERS № 1 SET № 2 SET № 3 SET
TURBO-ALTERNATORS № 1 SET № 2 SET № 3 SET
S. F. BOILERS (3) BOILERS FANS ETC.
P. F. BOILERS (3) BOILERS FANS ETC.
COAL HANDLING PLANT ASH CRANE COAL CRANE 1 COAL CRANE 2 COAL BRIDGE AND CRANES BELT CONVEYORS G. BUCKET CONVEYORS
PIPE WORK L.P. H.P.
CENTRAL EVAPORATING PLANT
PUMP HOUSE PUMPS ETC. SCREENS SLUICES
ELECTRICAL EQUIPMENT
MAIN SWITCH GEAR 132 K.V. 66 K.V.
AUXILIARY SWITCH GEAR
TRANSFORMERS 66 K.V. SW. HOUSES TRANS. ANNEXE
CABLING
HEATING AND LIGHTING
1000 75 50 25 900 75 50 25 800 75 50 700 75 50 25 600 75 50 25 500 75 50 25 400 75 50 25 300 75 50 25 200 75 50 25 100 75 50 25 00
NUMBER OF MEN EMPLOYED BY MAIN CIVIL ENGINEERING CONTRACTORS
£
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
00
ERECTING PILE FRAMES
9 BORE PILES
4 BORE PILES
(TOTAL 743 PILES)
FLOOR
SEALING AND CAULKING IN FREE AIR
ERECT STAGING AND CAISSONS
SINK
SINK SHAFT AND SEAL
CAULK IN FREE AIR
CAULK IN FREE AIR
ERECT SHIELD
TUNNEL
GROUT AND CAULK
CONCRETE AND DISMANTLE SHIELD
TUNNEL FLOODED 24TH AUGUST. (U.S. TUNNEL CANCELLED DUE TO WAR)
TUNNEL FLOODED 17TH NOVEMBER
DREDGING
STAGING ETC.
PRE-CASTING COMMENCE
SINK AND PLACE
FENDERING
BRACING AND FENDERING
CRANE RAILS
EXCAVATION, CONCRETE BASE
SHEET PILING
CONCRETE
NIGHT SHIFT
AND DAY SHIFT
BRICK LINING
(78 PILES)
SHUTTERING ETC.
30,000 K.W. (PARSONS)
30,000 K.W. (PARSONS)
60,000 K.W. (B.T.H.)
CONCRETING
PAINTING (ALL THREE)
EXCAVATION
H.T. AND PRECIPITATOR HOUSES ETC. SUPERSTRUCTURES (SUB-CONTRACT)
ACCOMMODATION BUILDING SUPERSTRUCTURE
CONTINUED INTERMITTENTLY
PILES AND FOUNDATIONS FOR TERMINAL TOWERS
5 CABLE CROSSING TUNNELS UNDER ROADWAY
ASPHALTE
SIEGWART P.C. ROOF
BUNKER ERECTION
DELIVERY
ERECTION
CONVEYOR HOUSE AND FAN ANNEXE
GUNITE LINING TO BUNKERS
DATE OF CONTRACT COMPLETION
COMMERCIAL LOAD ON STATION
CONTRACT 2 LABOUR
ERECTING FOUNDATION STEELWORK
№ 1 SET ON COMMERCIAL LOAD 1-12-1939
№ 2 SET ON COMMERCIAL LOAD 3-10-1939
WORK CONTINUED ON № 3 SET, COMMERCIAL LOAD 8-4-1941
№ 2 VALVE FLOATED, FEB. 12TH 1940
№ 4 VALVE FLOATED, MAR. 21ST 1940
№ 6 VALVE FLOATED NOV. 8TH 1940
№ 1 VALVE FLOATED, MAR. 4TH 1940
№ 5 VALVE FLOATED, SEPT. 22ND 1939
№ 3 VALVE FLOATED, OCT. 27TH 1939
MINOR FINISHES
TIPPLER PIT
DELIVERY COMMENCED
FOUNDATIONS AND BUILDINGS CONTRACT 2 MONTHLY CERTIFICATES
CONTRACT 1 LABOUR
C.E.B. LOOPED IN 18TH JULY 1939
ERECTING MAIN M.V.E. SWITCHGEAR
ACCESS ROADS & RLYS. CONTRACT 1 MONTHLY CERTIFICATES
MAIN CABLING COMPLETE