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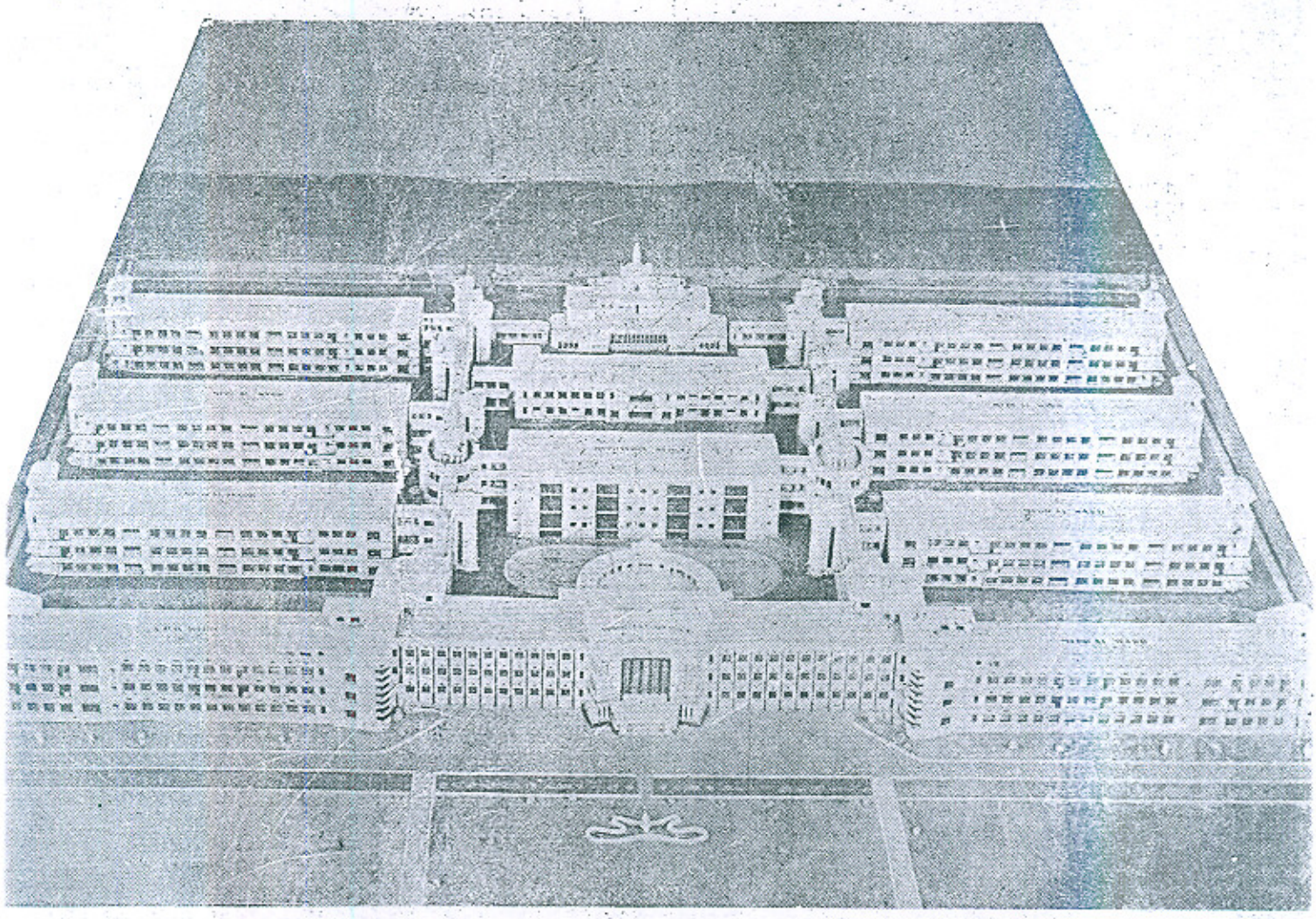

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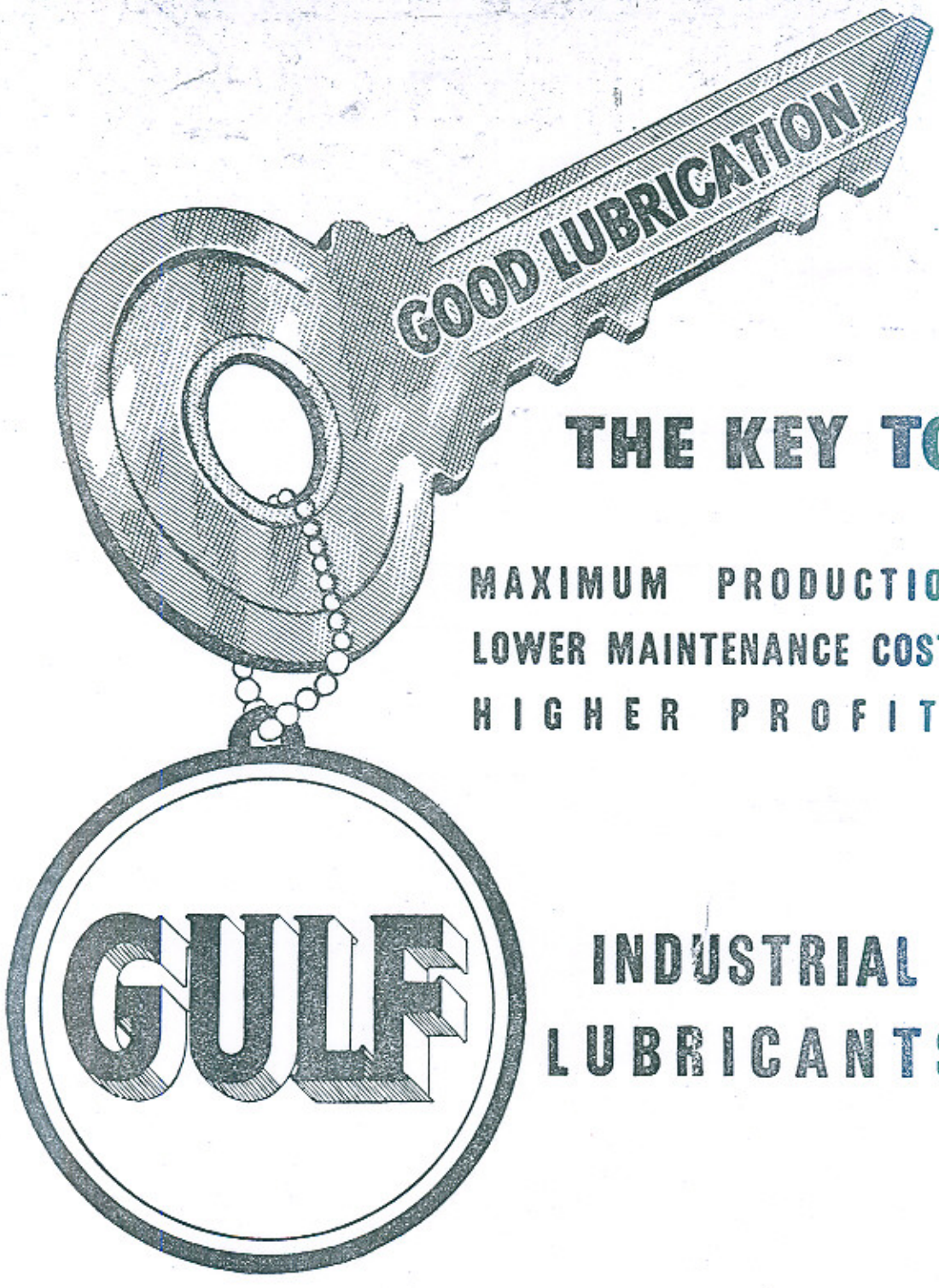
( an aerial view of the project )

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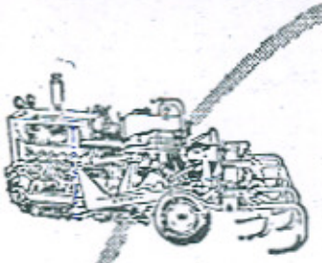

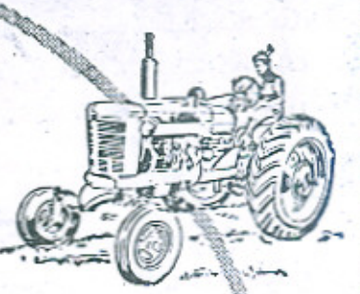

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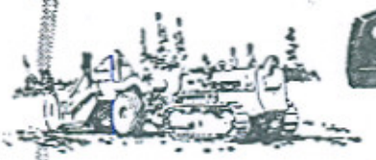

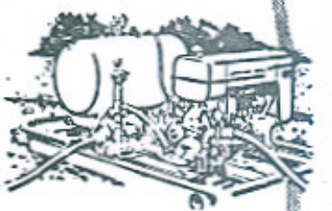

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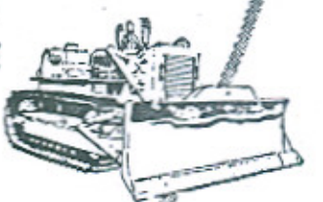

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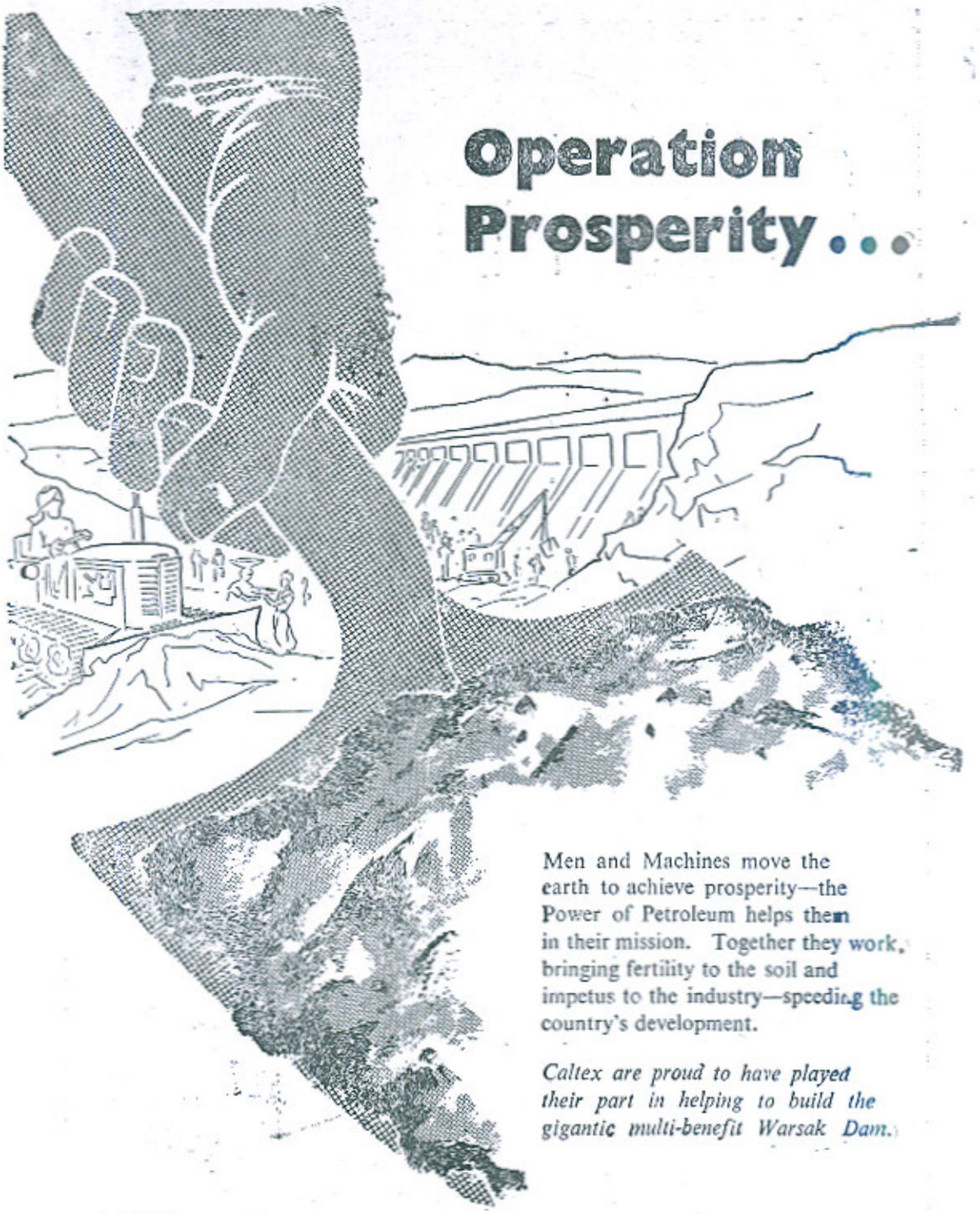

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*With them the Seed of Wisdom did I sow,*
*And with my own hand labour'd it to grow:*
*And this was all the Harvest that I reap'd-*
*I came like Water, and like Wind I go.*

"Omar Khayyam"

In this age of industrialisation factory engineers' approach to their problems is not so very different from the philosophy of Omar Khayyam. There is no time to waste—that is why management and production experts are always alert and keep a constant check on all operations. Every factory problem is carefully examined to achieve mechanical and economic efficiency.

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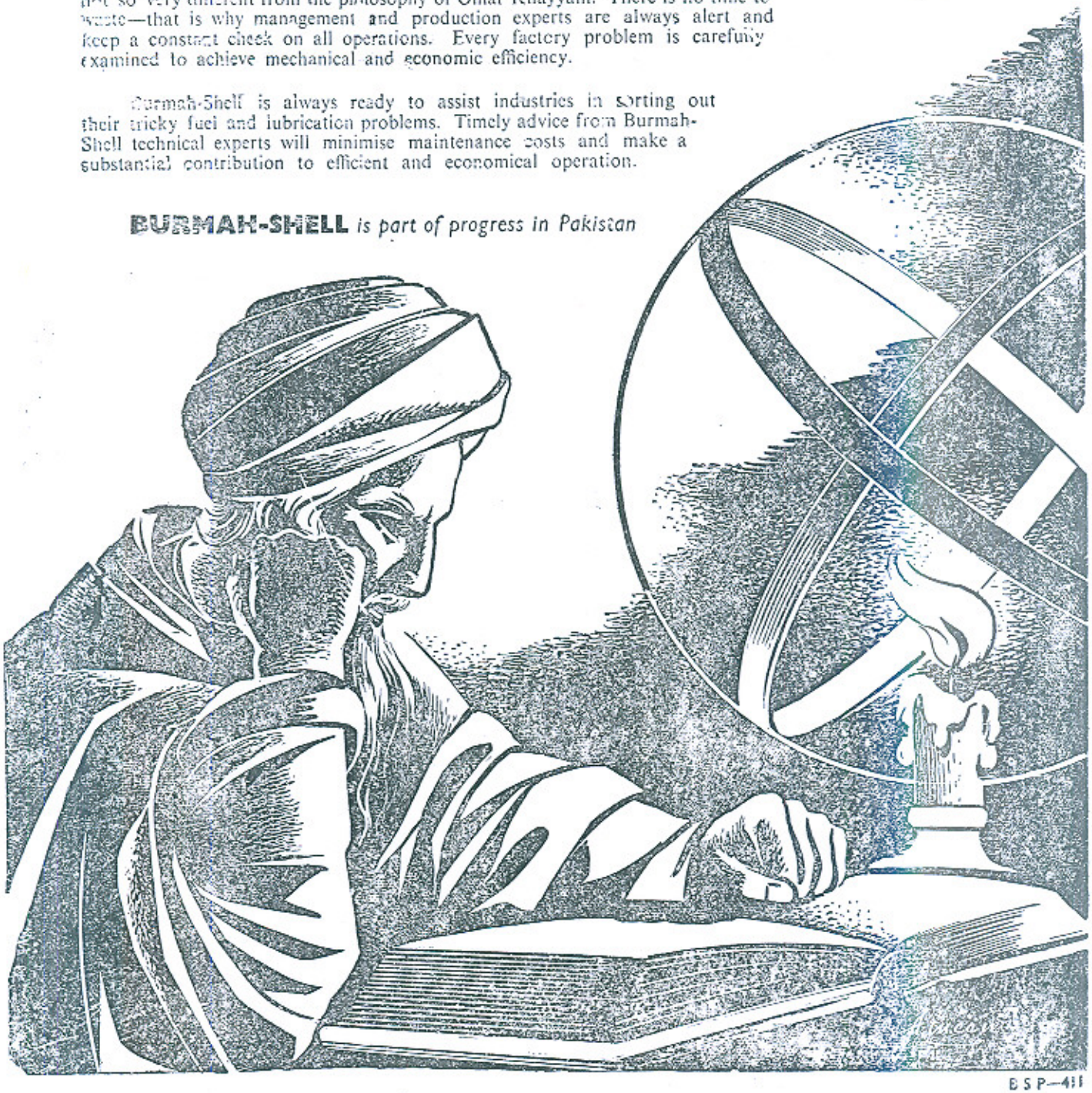

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# A FEATURE ON THE WARSAK HYDRO-ELECTRIC PROJECT

SERIES—6

## DESIGN OF CONCRETE MIXES

By

**Mian Irshad Nabi, P.S.E.I.***

*Arbitrary proportioning of concrete ingredients so commonly employed on almost all our Projects gave way to proper Design of Concrete Mixes used on Warsak Dam Project. This step resulted not only in the economy of Cement, but produced several relationship depicting properties of concrete as affected by Warsak aggregates and other ingredients under local conditions. It was also felt that certain data which is so vital in the preliminary design of Concrete Mixes which would suit the conditions and requirements of structures in Pakistan did not at all exist, because of no efforts on the part of our Engineers in the past and even now to give due attention and importance to the field of Concrete Technology, which it so emminently deserves. It is time now that something is done to improve the methods and system of making and controlling concrete at home. The field control of concrete is most important, and on this depends the ultimate quality of concrete in place. Concrete properly designed, but without any field control is no better, may be worse, than the so-called arbitrary proportioning. It would be unwise to think that such a rigid control in the production of good quality concrete would increase the first cost, but experience has shown that it is on the contrary.*

### INTRODUCTION

THE design of concrete mixes is the determination of most economical and practicable combination of available aggregates, cement, water and in some cases admixtures that will produce a mixture having the required degree of workability and which will develop required qualities on hardening. The oldest and most used form of proportioning is that in which fixed proportions of cement, sand and coarse aggregate are arbitrarily selected. Generally speaking this type of proportioning has proved satisfactory and economical on small works, but undoubtedly it cannot be practiced on large works such as Warsak Dam Project; where about 7,00,000 cubic yards of concrete would be consumed. A small amount of cement saved per cubic yard, as a result of proper design, research, and experiments could easily bring about a saving of few million rupees, apart from several other benefits which would accrue from the produce of good quality concrete. Arbitrary proportioning would at times produce under-sanded, harsh concrete due to bulking of sand, which would be difficult to work, thus causing segregation and honeycombing in concrete placed. Then there is complete uncertainty about obtaining more or less constant water cement ratio; which is the main cause for varying compressive strength of concrete, the least desired in a durable concrete structure. There is always a problem of maintaining constant yield per

*Executive Engineer, Warsak Dam Project.

unit volume of cement used. On most of the work sand is invariably supplied moist, which when used in bulked state, as it is always done, reduces the yield, which means consumption of more cement, in other words raising the cement content unnecessarily. The foregoing points therefore make it amply clear, that in this modern age, to secure good quality concrete the yoke of old-fashioned proportioning in this country must be taken off, to be replaced with something more becoming. It will not only bring this country uptodate in this field of engineeing but will pave way to the establishment of certain very important and useful data for the guidance of our future generation.

The subject of concrete Technology unfortunately has been uptil now, completely neglected in this country; so much so that concrete on big Projects has been poured without any design or control, of any sort. However a beginning was made with the commencement of Warsak Dam which will serve as a stepping stone for future project.

## BASIC CONCEPT OF DESIGN

The mix design for Warsak Project was based on the fact that the volume of mixed concrete is equal to the sum of the absolute volumes of its components. Thus if

W = Absolute Volume of water in a concrete mix.
C = Absoulte volume of cement.
A = Absolute volume of fine aggregate.
B = Absolute volume of coares aggregate.
V = Absolute volume of entrained air.
then $W+C+A+B=1$ for Normal (Non-Air-Entained) Concrete.
and $V+W+C+A+B=1$ for Air-Entrained Concrete.

There is some entrapped air even in the normal concrete the percentage of which is so small that it can be disregarded.

### Design Proceedure for Plain Concrete Mixes

In designing a concrete mix the procedure adopted is contained in the folowing 9 steps.

1. (*a*) Selection of W/C ratio for required durability.
   (*b*) Selection of W/C ratio for strength requirements.
2. Selection of slump in terms of consistency.
3. Selection of the maximum size of aggregate.
4. Determination of optimum sand percentage of total aggregate for required workability.
5. Unit water content, to satisfy the requirements in 1-4 above.
6. Determination of cement content having known the unit water content in (5) and W/C ratio in (1) above.
7. Determination of the absolute volumes of each ingredient using their specific gravities.
8. Conversion of absolute volumes into their respective weights.
9. Adjustments.

### STEP I. Selection of Water-Cement Ratio & Water-Cement Ratio Law

Before anything is said about the selection of W/C ratio it is very important at this stage that the water-cement ratio law is explained as this forms the foundation of good quality concrete. The law states that for *plastic* mixtures using sound and clean aggregates the strength and other desirable properties of concrete under *given job conditions* are governed by the quantity of mixing water per bag of cement. Note the words plastic mixtures which is a prerequisite for the law to hold good, therefore the concrete must be plastic and workable so that it could be readily moulded into a compact dense mass without any segregation. Too wet or dry concrete mixes which are difficult to work and place in forms without causing segregation and rock pockets, would not follow the general relationship advocated by the W/C ratio Law. The other limitation is in respect of given job conditions which is under-stood to mean kind of concrete material that are used, uniformity of proportioning concrete ingredients, efficiency of mixing and placing, curing conditions such as temperature and moisture and so on.

In the selection of W/C ratio for durability requirements use of Table 1 was made, whereas for compressive strength requirements, W/C ratio was adopted from the job curves which were established on the results of trial mixes carried out in Concrete Control Laboratory at Warsak

using aggregates and cement to be used on this Project, Figs. 1 and 2. The origin of Table 1 is the service record of various concrete structures built uptodate. The concrete structures built several years back have been watched as to how well they have stood upto weathering agents. In case of satisfactory service it was assumed that W/C ratio used for the structure was adequate for durability requirements. Thus there exists a definite relationship between W/C ratio and durability of the structure. It is very essential in Pakistan that a Table on similar lines is formulated after obtaining sufficient data on the subject. A suggestion, therefore, is made, with a request to all Government Departments and other Organisations executing Concrete Projects to maintain a complete record of W/C ratio used on various works, with an additional information in way of type and brand of cement used, location and nature of concrete aggregates, for it is quite probable that where, in fact the W/C ratio had been adequate for the structure the deteriora-

## TABLE 1

**Net Water-Cement Ratios for Various Types of Construction & Exposure Conditions**

| TYPE OR LOCATION OF STRUCTURE | MILD CLIMATE, RAIN SEMI ARID, RARELY SNOW OR FROST |
|---|---|
| A. Concrete in portions of structures subject to exposure of extreme severity, such as the top 2 ft. of walls, boxes, piers and parapets, all of curb, sill, edges, copings, cornices, and concrete in the range of fluctuating water levels or spray. These are parts of dams, spillways, wasteways, tunnel inlets, and outlets, tailrace walls, valve houses canal structures and other concrete work. | 0.55±0.02 |
| B. Concrete in exposed structures and parts of structures where exposure is less severe than A, such as portions of tunnel linings and syphons subject to freezing, the exterior of mass concrete and other exposed parts of structures not covered by A. | 0.55±0.02 |
| C. Concrete in structures or parts of structures to be covered with backfill or to be continually submerged or otherwise protected from weather such as cut off walls, foundations and parts of substructures, Dams, Trash Rocks, Gate chambers outlet works, and control houses. | 0.58±0.02 |
| D. Concrete that will be subject to attack by sulphate alkalies in soil and ground waters and will be placed during moderate weather. | 0.50±0.02 |
| E. Concrete doposited by Tremie in water. | 0.45±0.02 |
| F. Canal lining. | 0.45±0.02 |

*Adopted from Conerete manual, United States Bureau of Reclamation, Sixth Edition 1956.

tion and scaling in the concrete might have taken place from cement or defective aggregates ; or chemical reaction between the two, well known as "Alkali-aggregate reaction." Warsak Project will contribute sufficient data in this respect.

The Figures 1 and 2 depict the W/C ratio-compressive strength curve for Air and Non-Air entrained Concrete at different ages *viz.*, 7, 28, and 90 days. These are very important curves and selection of W/C for strength requirements was based on these. On a big Project job curves are established first, but where such arrangements do not exist, Concrete Designer is quite in the dark as to what W/C ratio he should select for a particular strength to design his concrete mix. It is therefore necessary that a relationship should be established between compressive strength and water-cement ratio of concrete made with concrete aggregates of all available sources and cement manufactured in Pakistan. This would result in one curve which could be safely used anywhere in Pakistan for the preliminary design of

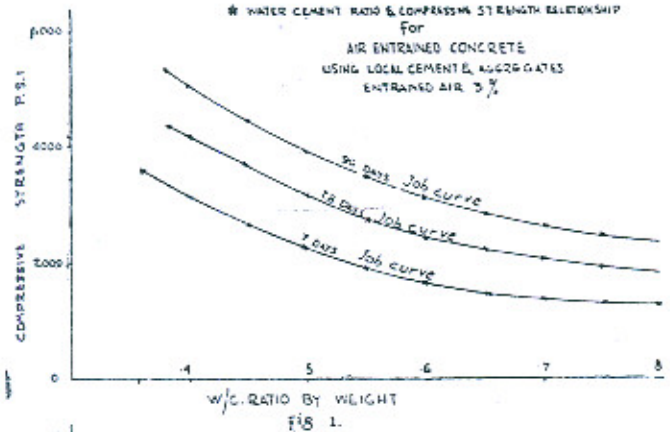

FIG 1.

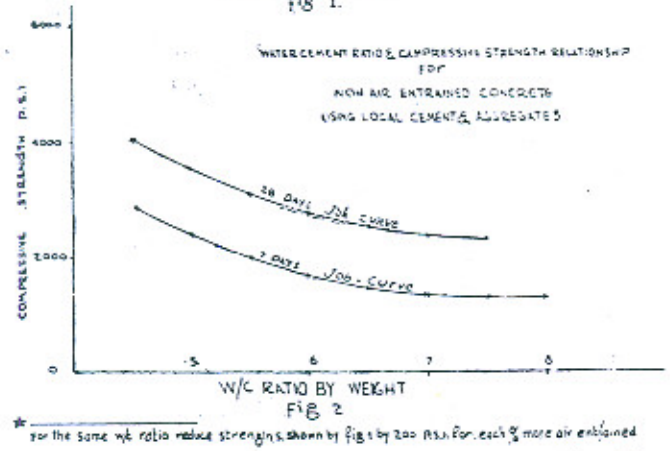

FIG 2

* For the same w/c ratio reduce strengths shown by figs by 200 P.S.I. for each % more air entrained

a concrete mix. Unlike the suggestion made for the establishment of Table 1, such a curve would be best established in some Concrete Laboratory, rather on the information collected from different Projects.

### STEP 2. Selection of Slump

The selection of slump would depend upon the dimensions of the structure, intensity of reinforcement, handling and placing equipment. From the standpoint of good quality concrete lowest possible slump compatible with job conditions should be used because this step would ensure the least water content which means lowest water-cement ratio for that particular mix. Nonetheless conditions are created at Projects which cause the adoption of higher slumps than necessary, but the practice of making the slumps suit the requirements of placing and handling equipment should never be followed, instead the placing and handling should be guided by the slump prescribed for the work. In general let Table 2 be the guide where slump is to be selected for various types of construction.

### STEP 3. Selection of Maximun size of Aggregate

The effect of using largest maximum size of aggregate in a concrete mix is reflected in its water requirements as shown by the following trial mixes and Figs 3 and 4 carried out in the Concrete Control Laboratory, Warsak Dam Project.

For the same workability, at about constant cement factor, the water requirement decreases with the increase in maximum size of aggregate. This is partly due to less surface area presented by the coarser aggregate in a mix and partly due to less percentage of sand necessary for obtaining the same workability : by virtue of fewer voids in larger size aggregate. In addition to the reduction in water requirements cement is also reduced, using large size of aggregate for the same workability and water cement ratio. Thus it is economical to use the largest *practicable* maximum size of aggregate available. However, in practice the selection of the maximum size of aggregate would be governed by the mixing,

| Trial Mix No. | Water per Cu. yd. | Cement per Cu. yd. | W/C | Entrained Air % | Slump inches | Maximum Size Agg. | Sand % | Concrete Temperature |
|---|---|---|---|---|---|---|---|---|
| A—155 | 222 | 550 | 0.40 | 3.4 | 3" | 4" | 20 | 86F° |
| A—211 | 252 | 600 | 0.40 | 4.8 | 3" | 2" | 30 | 69F° |
| A—215 | 278 | 550 | 0.56 | 5.3 | $2\frac{1}{2}$" | $\frac{3}{4}$" | 40 | 70F° |
| A—127 | 195 | 350 | 0.56 | 4.0 | $2\frac{1}{2}$" | 4" | 25 | 92F° |

handling and placing considerations, thickness of the section; and spacing of reinforcing bars. At Warsak Dam Project, the largest maximum size of aggregate selected was 4 inch. This was mainly dictated by the availability factor. The aggregate deposits, which supplied the aggregate could yield this size as its maximum. However, it would have been more economical to have used 6 inch aggregate provided it was available in sufficient quantity. Having decided the maximum size, coarse aggregate was proposed to be used in three sizes *viz.* 4"-2", 2"-$\frac{3}{4}$", $\frac{3}{4}$" $\frac{3}{16}$". This division automatically gave three maximum sizes of 4", 2" and $\frac{3}{4}$" to be used on various works at Warsak Project, depending upon the intensity of reinforcement and dimensions of the structure. As a matter of practice, maximum size of aggregate to be used on a work is determined by the dimensions of the structure and intensity of reinforcement, as explained earlier and for that purpose table 3 should be used.

## TABLE 2*

**Recommended Slumps for Various Types of Construction**

| TYPE OF CONSTRUCTION | SLUMP | |
|---|---|---|
| | Maximum | Minimum |
| Reinforced foundation walls and footings ... | 5" | 2" |
| Plain footings, caissons and Substructures Walls ... | 4" | 1" |
| Slabs, Beams and reinforced walls ... | 6" | 3" |
| Building Columns ... | 6" | 3" |
| Pavements and Tunnel Inverts ... | 3" | 1" |
| Heavy mass construction ... | 3" | 1" |
| Tunnel Arch ... | 6" | 4" |

*Adopted from Design of concrete mixes A.C.I. Standard 613-14.

## STEP 4. Determination of Optimum Sand Percentage

The optimum percentage of sand is that quantity which when combined with coarse aggregate and other ingredients of a concrete mix will produce the desired workability and at the same time uses minimum amount of water. Thus in a concrete mix using a particular type of coarse aggregate there is an optimum percentage of sand and that smaller or greater percentage than this would require more cement paste. The optimum percentage of sand in a mix varies with the maximum size of aggregate, particle shape of sand and coarse aggregate used. Trial

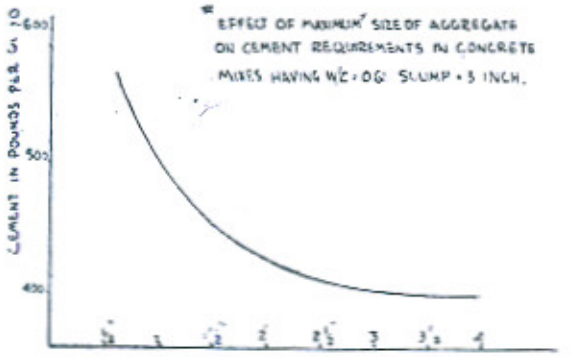


Fig 3

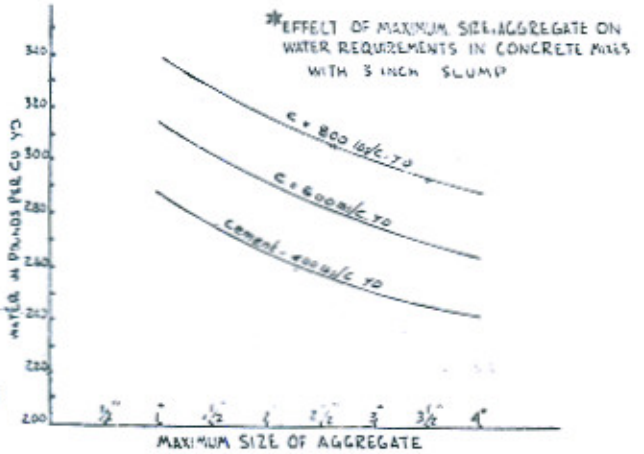


Fig 4

* stone was from Area "C" sand area & F.S. 3/4 sizes crushed in mixes using 3/4" max. size aggregate results taken from trial mixes A-226 to A-294 conducted at Conc. Control Lab. Warsak Dam Project

mixes using Warsak aggregates were conducted in the Concrete Control Laboratory to establish the optimum percentage of sand required for various sizes of aggregates to meet the desired workability. The curves shown in Fig. 5 established as a result of these trial mixes supplied necessary data in respect of optimum sand percentage for the preliminary design of concrete mixes at Warsak Dam Project. It was noticed that in order to obtain the same workability, the sand percentage could be decreased by 1 percent for a corresponding decrease of .05 in water cement ratio and vice versa. The study of the curves also reveal that for any given water cement ratio and workability the optimum sand percentage increases with the decrease in maxmum size of aggregate and particle shape. The particle shape in case of crushed $\frac{3}{4}$"-$\frac{3}{16}$" stone, has caused the optimum sand percentage to go up as shown by the curve I-S in Fig 5. No efforts were made to establish the curves for optimum sand percentage, in concrete mixes using 6", 3" and $\frac{1}{2}$" maximum size of aggregate, partly because some sizes were not available and partly some were not to be used on the Project. However, a Concrete Designer is advised to interpolate from the curves presented for obtaining his figures for the required maximum size aggregate. The coarse aggregate in all the trial mixes was rounded, natural river gravel from Area "C", unless stated otherwise on the curves.

## STEP 5. Selection of Unit Water Content.

The next step is to select water content per Unit Volume (1 cu. yd.) of concrete which would give the desired workability and consistency so as to satisfy the requirements mentioned in Step 1 to 4 above. The water requirements per cubic yard of concrete at various water-cement ratios, for a constant slump of 3" using Warsak aggregates is shown in Figure 5. These curves were also established on the results of trial mixes carried out in the Concrete Laboratory at Warsak Dam Project. These water contents per cubic yard of concrete selected from the curves hold good for certain set of conditions, which are listed below :—

1. Concrete temperatures 85°-87°F.

2. Slump of concrete to be 3 inches.

3. Fineness modulus of sand = 2.75 and that sand percentage is optimum.

4. Pass 100 material not greater than 10%.

5. Coarse aggregate to be natural, rounded gravel (curves, IA, II, III, IV, & V).

It, therefore, appears that certain adjustments would have to be made to the figures thus obtained from the curves, when concrete is manufactured under different set of conditions. The water requirement of a concrete mix is found

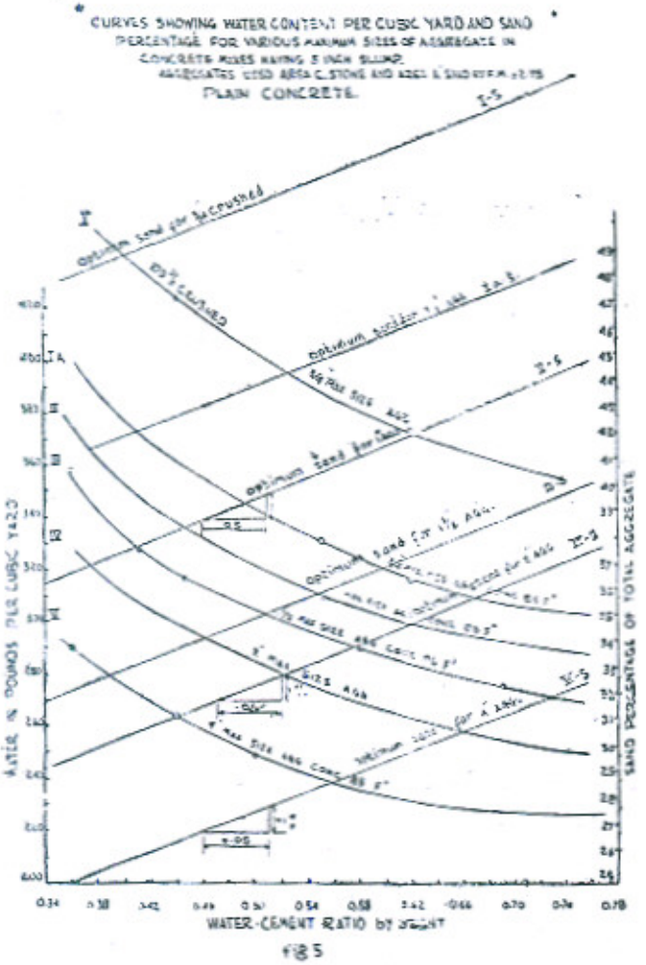


FIG 5

* Stone was from area "C" sand area "A" [illegible] crushed [illegible] represented by curve [illegible] results taken from trial mixes [illegible] conducted at [illegible] control laboratory Warsak Dam Project aggregates [illegible] average grading

to increase with the increase in slump and temperature of concrete, increase in percentage of sand, pass 100 material in sand and when crushed aggregates are used. It became necessary therefore that adjustment factors for the various conditions mentioned above are determined so as to facilitate the preliminary design. The adjustment factors are given in Table 4, established on the results of trial mixes conducted in the Concrete Laboratory at Warsak Dam Project.

STEP. 6, 7, 8, & 9.

These steps consist in mere calculations which are explained in the example detailed on the pages to follow.

### Design Procedure for Air-Entrained Concrete Mixes.

The same design procedure as explained for plain mixes was followed for the design of air-entrained concrete mixes with the exception that unit water content and optimum sand percentage was calculated by applying the following correction factor to the figures obtained for plain concrete mixes. For each 1% increase or decrease of air-content, water content be decreased or increased by 8 pounds per cubic yard, and sand decreased or increased by 1%. This sadjustment factor is included in Table 4.

### EXAMPLE

Mix Design for Main Dam Core Concrete, Warsak Project.

DATA.

Compressive strength of concrete desired at 28 day = 2000 P.S.I.

| | | |
|---|---|---|
| Specific Gravity of cement | = | 3.13 |

FINE AGGREGATE.

Source Area A.

| | | |
|---|---|---|
| Specific Gravity | = | 2.80. |
| Absorption Factor | = | 1.0%. |
| Fineness Modulus. | = | 2.75. |

COARSE AGGREGATE.

Source Area C.

Rounded natural river gravel.

| | | |
|---|---|---|
| Specific Gravity. | = | 2.70. |
| Absorption Factor. | = | 0.2%. |
| Air-Entraineed. | = | 4%. |

**STEP 1. Selection of W/C Ratio for Durability and strength requirements.**

For durability requirements, Table 1 gave a maximum water-cement rati of 0.60 and minimum of 0.56 whereas job curve for Air-Entrained Concrete figure 1 gave a W/C ratio of 0.63 (2300 P.S.I. for 3% air, reduced to 2100 for 4%).

Another consideration in the selection of W/C ratio specially for the Core Concrete of a Dam is the cement content which should be the least possible for controlling the heat generation due to hydration of cement. Therefore, a water-cement ratio of 0.63 as against 0.60 which would have been otherwise preferred, was selected.

This step was taken in favour of reducing the cement content, though durability requirements for the concrete were waived slightly in view of the fact that Core Concrete were unexposed and shielded by face concrete.

**STEP 2. Selection of Slump.**

Table 2 suggested 1 to 3 inch slump for heavy mass construction. Taking advantage of Air-entrainment a slump of 2 inch was finally selected, which would give ample workability and placeability.

**STEP 3. Selection of Maximum Size of Aggregate.**

The maximum size of aggreate selected was 4 inch as explained earlier in Step 3 under design procedure.

## TABLE 3*

**Maximum Size of Aggregate Recommended for various Types of Construction**

| Minimum Dimension of Section (inches) | MAXIMUM SIZE OF AGGREGATE IN INCHES FOR | | | |
|---|---|---|---|---|
| | Reinforced Beams Walls & Columns | Un-reinforced Walls | Heavily Reinforced Slabs | Lightly Reinforced or unreinforced Slabs |
| $2\frac{1}{2}-5$ | $\frac{1}{2}-\frac{3}{4}$ | $\frac{3}{4}$ | $\frac{3}{4}-1\frac{1}{2}$ | $\frac{3}{4}-1\frac{1}{2}$ |
| $6-11$ | $\frac{3}{4}-1\frac{1}{2}$ | $1\frac{1}{2}$ | $1\frac{1}{2}$ | $1\frac{1}{2}-3$ |
| $12-29$ | $1\frac{1}{2}-3$ | 3 | $1\frac{1}{2}-3$ | 3 |
| 30 or more | $1\frac{1}{2}-3$ | 6 | $1\frac{1}{2}-3$ | $3-6$ |

*Adopted from Design of concrete mixes A.C.I. Standard, 613-44.

## TABLE 4

**Adjustment Factors for Curves I To V in Fig. 5**
*(For trial mixes or estimating purposes only)*

| CHANGES IN CONDITIONS | ADJUSTMENT FACTORS | |
|---|---|---|
| | Sand Percentage | Unit Water Content |
| 1. Each 0.10 increase or decrease in F.M. of sand ... | ±0.5 | ... |
| 2. Each 1 inch increase or decrease in slump ... | ... | ±3% |
| 3. Each 1% increase or decrease in sand percentage of T.A. | ±1 | ±2.5 lbs. |
| 4. Each 1 degree farenheit increase or decrease in conc. temp. | ... | ±1 lbs. |
| 5. Using crushed or manufactured aggregates ... | +6 | +35 lbs. |
| 6. Each 1% increase or decrease in air content ... | ±1 | ±8 lbs. |

### STEP 4. Determination of Optimum Sand Percentage.

From the curve V-S for 4 inch maximum size aggregate in Figure 5 optimum sand percentage at 0.63 water cement ratio for plain concrete mix is 30%. Applying the correction factor, that decrease sand by 1% for each percent of air-entrained the optimum sand percentage for 4% air-entrained concrete mix was fixed at 26% of total aggregate.

### STEP 5. Selection of Unit Water Content.

Referring to Curve V in figure 5, the unit water content is 230 pounds per cubic yard for non-air-entrained concrete mix having 3 inch slump at 86°F concrete temperature. This water is reduced with the application of rule (6) in Table 4 to meet the requirements of air-entrained concrete. Thus the water reduces to (230-32) 198 pounds per cubic yard to give 3 inch slump. Since the desired slump is 2 inch the water content was further reduced as per rule (2) in Table 4 to (198-6) 192 pounder per cubic yard.

### STEP 6. Determination of Cement Content.

Having known the water cement ratio and unit water content, cement content, was found as follows :—

$$W/C = 0.63.$$

$$\frac{192}{C} = 0.63.$$

$$\therefore C = \frac{192}{0.63} = 305 \text{ Pounds per cu : yd.}$$

### STEP 7. Absolute Volumes.

Entrained air $= \frac{4}{100} \times 27 = 1.08$ cu. ft. per cubic yard of concrete.

Cement $= \frac{305}{3.13 \times 62.4} = 1.54.$ per cubic yard of concrete.

Water $= \frac{192}{62.4} = 3.08.$ per cubic yard of concrete.

Absolute Vol. of paste (V+C+W) = 5.70 per cubic yard of concrete.

Absolute Vol. of aggregates = 27-5.70 = 21.30 per cubic yard of concrete.

Absolute Vol. of sand.

$$= \frac{26 \times 21.30}{100} = 5.54 \text{ per cu. yd.}$$

Absolute Vol. of Coarse Agg. = (21.30-5.54) = 15.76 per cu. yd.

### STEP. 8. Conversion of Abs. Vols. into Weights.

Sand = $55.4 \times 2.80 \times 62.4$ = 968 pounds per cubic yard (S. S. D).

Coarse Agg. = $15.76 \times 2.70 \times 62.4$ = 2655 pounds per cubic yard (S. S. D).

Mix Proportions therefore are :—

192 : 305 : 968 : 2655

or 0.63 : 1 : 3.17 : 8.7

by weight on S. S. D. Condition.

A trial batch representing these mix proportions was made in the concrete control laboratory which gave $1\frac{3}{4}$ inch slump 2.75% entrained air with a slight tendency of the mix being oversanded thereby necessitating another trial batch in which sand was decreased by 1% which would reduce the water content per cubic yard by 2.5 pounds vide rule 3 in table 4.

This reduction in water would tend to reduce the slump which was not worried about because it was considered that boosting the air content to 4% would automatically maintain the slump.

The net water content = 192 - 2.5 = 189.5 pound per cubic yard optimum sand percentage = 25%.

$$C = \frac{189.5}{0.63} = 300 \text{ pouns per cubic yard.}$$

The rest of the calculations are similar to the previous one which gave the following six proportions.

189.5 : 300. 906 : 2721

or 0.63 : 1 : 3.02 : 9.07 by weight on S.S.D. condition.

The trial batch was made and the following results obtained.

Slum = $2\frac{1}{4}$ inch.

Air-entrained = 4%

Workability = Good.

The results being very close to the desired, the mix design was adopted for the Main Dam Core Concrete.

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# SOME ASPECTS OF THE ELECTRICAL DESIGN OF UNIVERSAL MOTORS

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UNIVERSAL motors have three outstanding advantages compared with induction motors: (1) they can be used on both d.c. and a.c. supplies; (2) they can be made for operation at any speed within very wide limits, and (3) they are suitable for a wide range of speed control. They cannot compare on price, however, with the induction motor for operations within the latter's capabilities. Their characteristics make them suitable for many domestic appliance applications and, while d.c. supplies are becoming fewer, these motors can be used over a wide range of frequencies on a.c. supplies, it being quite common for them to be operable on d.c. and on a.c. at any frequency up to 60 c/s. They are an essential part of equipment, both domestic and industrial, with a production worth many milion pounds a year in this country alone.

## GENERAL ASPECTS.

The universal motor (Fig. 1) is a series wound, commutator machine suitable for use on both d.c. and a.c. single-phase supplies and entirely confined to small fractional horsepower sizes, particularly in appliances such as vacuum cleaners, floor polishers, hair dryers and portable drills. The motors are made for outputs up to about 0.5 h.p., but are very seldom used in larger sizes owing to the serious commutation problem.

The universal motor is at its best as a high-speed machine, *i.e.* when running at about three times synchronous speed, when the power factor is near to unity and the performance is similar on both a.c. and d.c. supplies at the same voltage. Speeds of about 9,000 to 11,000 r.p.m. are quite usual in vacuum cleaners. The motor is not ideal at speeds below synchronous on a.c., though it can be made quite successfully to operate down to half this speed or even lower.

The difficulty in the low speeds is due to the rapid drop in the torque/speed characteristic resulting from the highly inductive windings required for low-speed working, as both field and armature have a large number of turns. Only a slight increase in load can cause a large fall in speed, and even stalling (Fig. 2). The discrepancy between the performances on d.c. and a.c. becomes very pronounced on such multiturn windings, so it is necessary to design for a.c. and add extra field turns for d.c. (Fig. 1b). As the effect is due to highly inductive windings, it is obviously worse on high frequencies than on low, so that the discrepancy between low-speed performance on a.c. supplies of different frequencies is also very pronounced.

As the induction motor can rival the universal machine for most applications where the speed is 2-pole synchronous or less, and is much cheaper, the lower limit of the universal motor tends to become about 3,000 r.p.m., except for special purposes. The upper limit in speed is probably about 20,000 r.p.m., and here the limit is due to commutation and bearing difficulties. Due to these problems, machines running at speeds above 10,000 r.p.m. have short time rated duties so that

carbon brush and bearing wear is not too

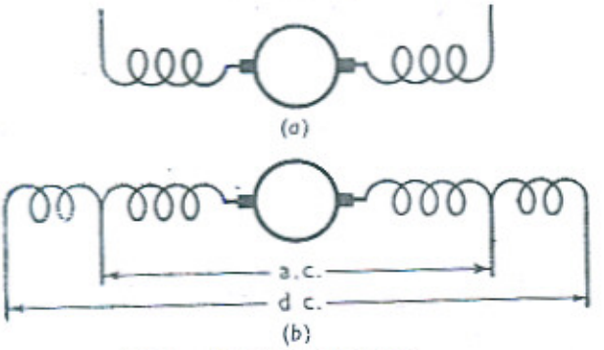
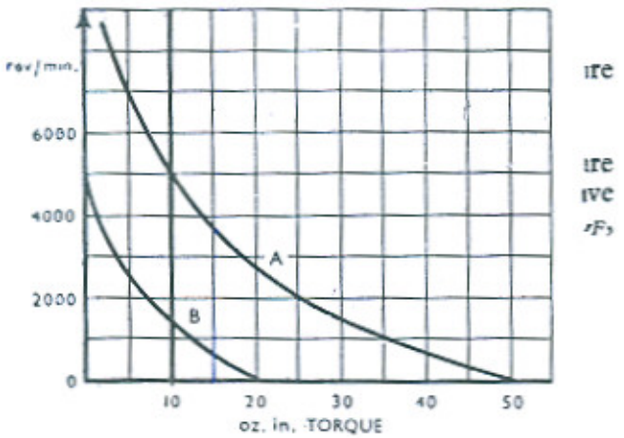



*Fig. 1.—Connection diagrams.*

rapid, *e.g.* the dometic appliances previously mentioned do not run for long periods nor very often, and this discontinuous duty relieves the problem of brush and bearing wear.

At about five times synchronous speed and above it is possible for the power factor to become leading. Comparatively few turns are required in the windings at these high speeds and the inductive volt-drops are much reduced. A study of the vector diagram (fig. 4) shows that low values of the volt-drops give quite a high armature back e.m.f., $E_r$, which can make the current I lead the voltage V, though not by very much.

The design of this machine is essentially that of the a.c. series motor, as it is an easy matter to cater for extra field turns for the d.c. working condition when required, this being necessary only on lower speed designs, *i.e.*, below twice synchronous speed. Compensating windings are used




Machine "A" designed for 10 oz in. at 5000 rev/min.
" "B" " " 10 oz. in. at 1500 "

*Fig. 2.—Torque/speed characteristics.*

on larger a.c. series motors but very seldom on small universal motors, and their use therefore is not considered here.

As commutation is one of the most difficult aspects of this type of motor, every effort must be directed to making conditions as easy as possible. To do this, the number of turns per coil under commutation is made as small as possible, which means having a large number of segments, slot permeances being kept low (*i.e.*, shallow wide slots large slot openings, commuttaion in the inter-polar space, short-pitched coils, etc.); but all these aspects are balanced against other requirements, *e.g.* large slot openings mean and increased Carter co-efficient, wide slots possibly mean increased armature diameter, and a large number of segments means a costly winding. All attempts to keep commutation difficulties within resonable bounds affect the cost of the machine very sensitively.

Examination of the problems discussed later, in the section on commutation, will show how the various parts and conditions affect the resultant voltage of commutation, and, as they have no compoles or compensating windings, it can be understood how much these little motors depend on good quality carbon brushes. It is a remarkable tribute to the carbon brush manufacturers that their products stand up so well to the very arduous conditions to which they are submitted in universal motors.

On cheaper products, where armatures with a small number of slots and segments are used, the sum of reactance and transformer voltages across the commutating coil might be as high as 12 to 14 volts peak; this is resisted by the brush contact drop to some extent, but the brush would be asked to cope with it and at the same time not to have too high a coefficient of friction, so that the temperature rise on a fast running commutator is not excessive.

The excellence of the carbon brush manufacturers' products is a big factor in the success of universal motors. Careful selection of the right brush for the job is most essential, and considerable time is devoted to testing to find the most suitable grade.

On account of the high speeds, small eccentricities or discrepancies in true running of the commutator can be serious, causing brush bouncing. Therefore spring pressures are kept high, sometimes up to 6 lb. per sq. in. on higher speed machines, and care is essential in choosing brushes with a suitable friction coefficient.

With undercut micas noise can be a nuisance and in many cases flush micas are used, but again care is required as the micas must wear with the copper or they will become proud, causing destructive sparking from a bouncing brush. The brush must, in these conditions, be capable of wearing down the mica as well as meeting its other problems.

Commutation must take place as far as possible while the short-circuited coil is passing through the inter-polar space in order to minimise the reactance voltage. This calls for very careful selection of the armature coil connection to the commutator as the brush box is usually fixed to the frame and no adjustment is possible. The best position for this connection being very critical on a.c. working, especially on slower speed motors, only a small tolerance can be allowed on the positioning of the commutator bars relative to the slots.

The armature core stampings are usually assembled so that the slots are skewed about I slot pitch. This tends to reduce the variation of the reluctance of the main flux circuit through the armature and reduces noise which could easily be caused by sudden changes of magnetic flux.

The design of the armature is similar to a normal d.c. type, but the stator for the field system, though having salient pols, must be built of laminations to suit alternating flux conditions. Many of these stators are now suitable for machine-winding of the field coils, and this must be borne in mind when shaping the pole shanks.

The iron parts of the flux circuit should not be saturated as this means a large number of turns for excitation and turns must be kept to a minimum; hence a small air-gap and large iron sections are required. High densities will lead to noise, as on all a.c. machines.

Owing to necessary production tolerances there are bound to be many machines with some eccentricity of the armature in the stator bore. This must be kept to a minimum, for the lateral pull on the armature will be stronger on the small gap side so that, with an alernating flux, there will tend to be hammering on the bearings. This tendency is much more pronounced on 4-pole than on 2-pole machines as the gap densities can have much larger discrepancies

To cater for any extra forces the bearings should be of ample area, with adequate lubrication.

## DESIGN ASPECTS.

### Main Problems of the A.C. Design.

Having estimated the physical sizes of the iron circuit to suit a chosen value of main flux with reasonable densities, such as a B max. of about 13,000 Maxwell/sq. cm. in good quality electrical sheet steel, there are four main problems to be examined.

(1) The inductive effects in the various parts of the windings.

- (*a*) $E_F$, the transformer voltage generated across the field coils by the main flux.
- (*b*) $E_A$, the transformer voltage generated across the armature winding by the main flux.
- (*c*) $E_C$, the transformer voltage generated across the armature commutating coils by the main flux.
- (*d*) $X_F$, the leakage reactance of the field winding.
- (*e*) $X_A$, the leakage reactance of the armature winding.

(2) Construction of the vector diagram, from a selected winding and a chosen value of main flux. The armature back e.m.f $E_r$, is finally obtained.

(3) From the value of $E_r$, in (2), the speed and torque are calculated from the appropriate formulae.

(4) A study of the commutating conditions is made, with calculations of the reactance and transformer voltages.

1 (*a*) *Field Transformer Voltage* EF.

The back c.m.f. induced across the field winding will be, assuming sinusoidal flux form $EF = 4.44\, f\, NF\varphi M\ 10^{-8}$ volts.

The voltage will lag $\phi M$ by $90_0$ thence the component of the applied voltage to supply this will be $-E_F$ shown in the vector diagram, and this leads $\phi M$ by 90°.

(*b*) *Armature Transformer Voltage EA.*

If the armature cross-field magnetic axis is at 90° to the main field axis, then the number of armature turns to the right of the main-field axis is the some as the number of armature turns to the left, and the resultant transformer voltage generated across the armature is zero as the voltages induced in the right and left parts cancel.

If, however, the armature cross-field axis is shifted, either by movement of the brushes or by connection of the coils to commutator segments further round, then there will be a greater number of coils in the arc between th main flux axis and the armature cross-field magnetic axis in the direction of movement of the brushes than in the opposite direction and a a resultant transformer voltage will appear at the armature terminals. Carrying this movement so far that the armature cross-field magnetic axis lies along the main flux axis, then all the armature coil are traversed by the main flux and the stransformer voltage would be similar in expression to that for the field turns, $E_F$, except that $\frac{N_A}{2a}$ would replace $N_F$.

It is evident that this transformer voltage varies according to the position of the

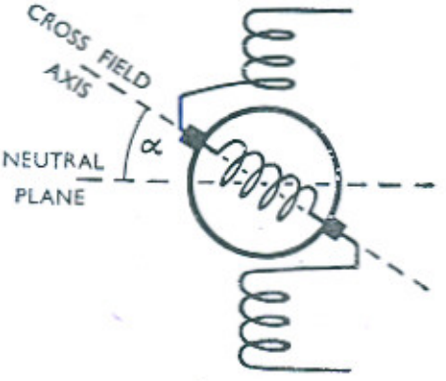



*Fig. 3.—Cross-field axis.*

armature cross-field axis, and (*a* being the angle between this axis and the neutral plane) $E_A$ will vary as sin *a* (fig. 3), and so we have $E_A = 4.44f \frac{N_A}{2a} \phi_M \sin \alpha\ 10^{-8}$ volts.

Again $E_A$ lags $\phi_M$ by 90° and so $-E_A$ will lead, and be in phase with $-E_F$.

(*c*) *Commutation Transformer Voltage,*

The armature coils undergoing commutation are in such a poslition, for best operating condition, that then embrace the main flux $\phi_M$ so that a transformer voltage is induced in these short-circuited coils.

Again, it will be influenced by angle $\alpha$ but as the coil embraces maximum flux area when $\alpha$ is zero and minimum when $\alpha$ is $90_0$, the commutating coil transformer voltage will be

$E_C = 4.44 f N_C \phi_M \cos a\ 10^{-8}$ volts,

where $N_C$ is the number of turns in the coil unddergoing commutation.

Again this voltage, will lag $\phi_M$ be 90° and so $E_C$ will be in phase with $-E_F, -E_A$.

There is, however, a further consideration regarding this voltage, because it exists in a closed circuit and therefore produces a current Ic which muft be rccounted for in the vector diagram.

The value and phace of this curren depend, on the resistance and reactance of the commutationg coil so that

$I_C = \frac{E_C}{Z_C}$, where $Z_C = \sqrt{R_C^2 + X_C^2}$

and lags Ec by the angle $\phi c$, where $\cos\phi c = \frac{R_C}{Z_C}$.

For allocating to the current vector, Ic must be multiplied by the transformation ratio $\frac{NC}{2N_P}$, so—$I'_C = I_C \frac{NC}{2N_P}$,

and for $\theta$ coils undergoing commutation at the same time—Ic will be $\theta$ times as large.

The vector is applied in direction from the end of the iron loss vector $I_I$.

As this transformer loss can be very severe, it is necessary to keep Nc low which, for a given value of $N_A$, means dividing the armature winding into as

large a number of sections as possible and a hence large number of commutator segments.

## LEAKAGE REACTANCE.

(*d*) *Field Coils*, $X_F$.

There are five main leakge paths:

(1) Pole sides to yoke through the coil.

(2) Pole tips to yoke.

(3) Pole tips to adjacent pole tips, through air.

(4) Pole tips to adjacent pole tips, across armature surface.

(5) End windings.

The permeance and inductance calculation are made for each section, and the sum of the five inductances gives the full field leakage inductance, $L_F$,

and $X_F = 2\pi f L_F$ ohms.

(*c*) *Armature Winding*, $X_A$.

Here again there are five main leakage paths:

(1) Cross-field path.

(2) Across the slots.

(3) Armature surface to pole face.

(4) Armature surface in interpolar space.

(5) End windings.

The sum of these five inductances give the full armature leakage inductance, $L_A$ and $X_A = 2\pi f L_A$.

The total machine leakage reactance is X, where $X = X_F \times X_A$ and the reactance drop = IX.

These reactance calculations are of great importance and it is necessary to get as accurate an estimate as possible of them. The ten reactance calculations are quite prolonged and tedious so it is not intended to go into them in this geneal survey but they will be the subject of a further article.

It will be seen, by a study of the reactance volt drops, that the larger they are the lower will be the power factor and the rotational e.m.f. $E_r$. Since the power output is porportional to $E_r$, the reactance values should be kept low.

As all the values include some figure of $(\text{turns})^2$, it is important to keep the turns as low as possible; this means using large iron sections and keeping the main flux as high as possible; also, leakage in air is reduced by long air paths, but both these tendencies mean a large machine with consequent expense.

Also, as mentioned before, the turns/coil, Nc, can be kept down by having a large number of segments, but again with consequent expense.

## THE VECTOR DIAGRAM.

In thase with the main flux vector $\phi_M$ is the magnetising current $I_M$ to a chosen current scale.

The value of $I_M$ is such that the field

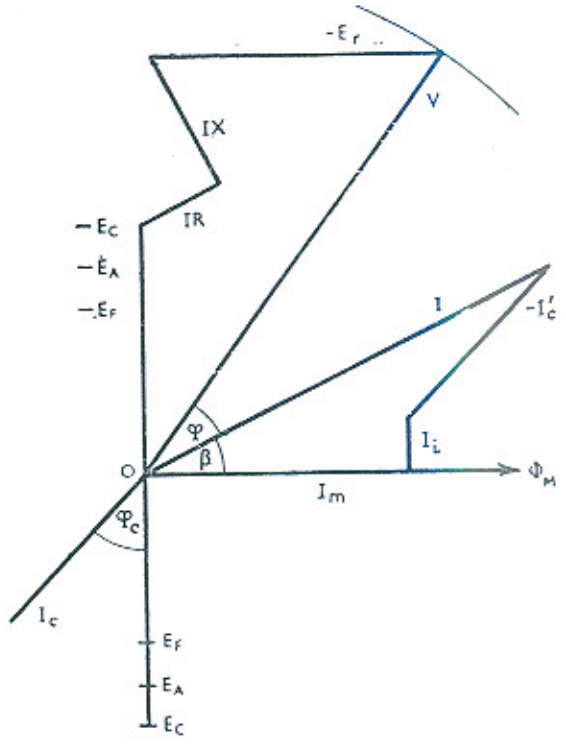



*Fig. 4.—Vector diagram.*

ampere-turns $I_M N_F$ provide the excitation for flux $\phi_M$. The iron loss current $I_i$ ic phase with $-E_F$, is drawn form the end of $I_\pi$. Form the end of $I_i$; the current due to transfomer acion on the short-circuited coils $-I'_C$ is drawn to scale and at appropriate angle.

The total line current I is the vector joining O to end of $-I'_C$. The voltage vectors $E_F$, $E_C$ and $E_A$ are drawn 90 lagging on $\phi_M$ and the components of the main supply voltage vector V must be drawn at 180° form these, $-E_F$, $-E_C$ and $-E_A$. As they are all in phase they are directly additive.

The resistance drop IR, where $R = R_A + R_F$, is drawn from the end of $-E_A$ and parallel to current vector I.

The leakage reactance dop IX,where $X = X_A + X_F$, is drawn from the end of IR and at right angles to the IR vector.

The final component is $-Er$, the e.m.f. induced in the armature wihding due to rotation, and this must close the voltage vectors to the supply voltage vectorV· As the rostational e.m.f.$Er$ is in anti-phase with. the main flux $\phi_M$, then $-Ea$is parallel to $M\phi$. Drawing a circle of radius V and drawing $-Er$ from end of IX, and parallel to$\phi_M$ till it cuts the circle of V will give the vector $-E_r$ in magnitude and direction. OV is the supply voltage V.

The angle⌀between vectors V and I, is the angle of lag of the current, and the power factor is cos⌀.

This is the vector diagram for one conditon of loading, the selected value of flux$\phi_M$ finally giving current I and the rotational e.m.f., $Er$.

Speed, $n$, can be readily calculated, from the value of E.

A new vector diagram shows that the smaller the induced voltages $E_F$, $E_C$, and $E_A$, and also the IR and IX volt drops, then the larger $E_r$ becomes, tending towards value V at the $I_m$ axis.

Power output is proportional to $E_r$. At very high speeds, when $N_F$ and $N_A$ are low, it is possible to have vectore V so far round towards $\phi_M$ that I becomes leading, especially if the $\phi_M$ iron loss $I_i$ is relatively large.

At the other end of the scale, the stalled condition is met when the IX vector meets the circle of V, then $E_r$ is zero.

## Rotational e.m.f. $E_r$ Formula.

The voltage induced across the ends of a coil rotating in a magnetic field is

$$e_r = -kw\phi \sin \theta$$

where $k$ is the ratio $\frac{f_n}{f}$ $\left(\begin{matrix} f_n = \text{speed frequency} \\ f = \text{supply frequency} \end{matrix}\right)$

$\phi$ the instantaneous flux value, and $\theta$ is the instantaneous position of the coil measured as an angle from the mid inter-polar to the plane of the coil.

As $\phi = \phi_M \sin wt$

$e_r = -kw\phi_M \sin wt \sin \theta$ for a single turn coil.

Extending this to a wound armature with $\frac{N_A}{2a}$ turns distributed over the armature surface per armature circuit, and the axis of commutation being at angle $a$ from the inter-poler neutral plane,

$$e_i = -\frac{N_A}{2\pi\alpha} kw\phi_M \sin wt \int_{\alpha}^{\pi+\alpha} \sin\theta \, d\theta$$

$$= -\frac{1}{\pi\alpha} kwN_A\phi_M \sin wt \cos\alpha.$$

The average value of the e.m.f.

$$= -\frac{1}{\pi^2\alpha} N_A kw\phi_M \cos\alpha \int_{o}^{\pi} \sin wt$$

$$= -\frac{1}{\pi^2\alpha} N_A kw\phi_M \cos\alpha$$

and the r.m.s. value

$$E_r = -\frac{1}{\sqrt{2}\pi\alpha} N_A kw\phi_M \cos\alpha \; 10^{-8} \text{ volts.}$$

The negative sign shows it to be opposite in phase to the main flux.

$$\text{As } N_A = \frac{Z}{2} \text{ and } kw \; \frac{2\pi np}{60}$$

$$E_r = -\frac{Zn\phi_M p}{\sqrt{2}\; 60\,\alpha} \cos\alpha \; 10^{-8} \text{ volt}$$

## TORQUE FORMULA.

The power into the rotor will be the product of the two components of voltage and current which are in phase with $\phi_M$, and the these $E_r$ and I cos $\beta$, where $\beta$ is the angle between I and $\phi_M$ vectors. So the watts input to rotor, less the copper loss, is

$$W_r = E_r \, I \cos\beta \text{ watts}$$

$$= \frac{Zn\phi_M p}{\sqrt{2}\; 60\alpha} I \cos\beta \cos\alpha \; 10^{-8} \text{ watts}$$

so torque $T_r = \frac{33000}{2\pi n} \frac{Zn}{746} \frac{\phi_M p I}{\sqrt{2}\; 60\alpha}$ cos $\beta$ cos $\alpha$ $10^{-8}$ lb. ft.

$$= 16 \frac{p}{\alpha} Z\phi_M \, I \cos\beta \cos\alpha \; 10^{-8} \text{ oz. in.}$$

Note that this is the torque calculated from the input to the rotor, and to output torque thes rotational loss torques must be subtracted form it, *i.e.* those for rotational iron loss, carbon brush friction, bearing friction and windage.

## REACTANCE VOLTAGE DUE TO COMMUTATION.

The current per conductor follows the sine wave value up to the moment B when commutation of a particular ciol commences (fig.5a).

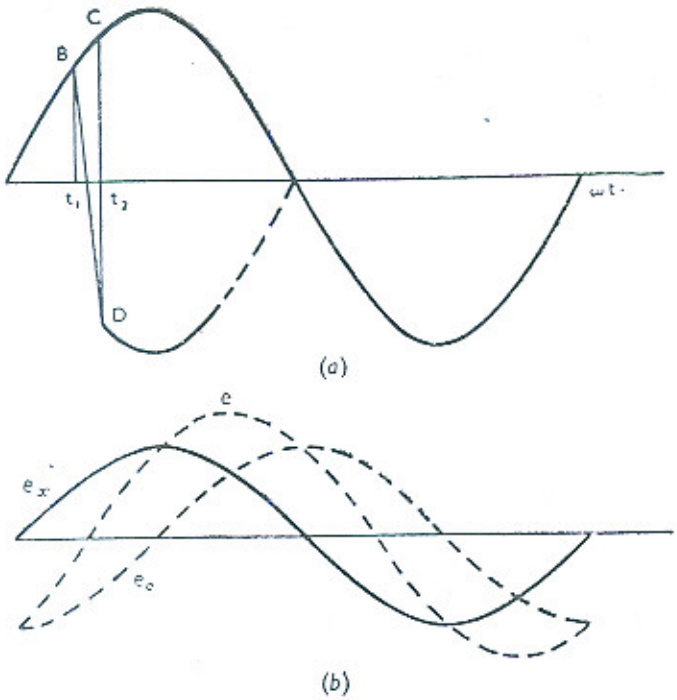



*Fig. 5.—Commutation during current wave (a), and voltages of commutation (b).*

The current reverses from B to D during the time of commutation, which ends $t_2$ when the current has the value it would have had at C but reversed, as at D.

Maximum value of conductor current = $I_M$

Instantaneous value of conductor current = $i$

Instant in time when commutation commences = $t_1$

Instant in time when commutation ends = $t_2$

Current in coil follows wave form.

$i = I_M \sin wt$ up to point B when it changes to a linear form $i = a\ t + C$ where $a$ and C are constants, during the time $(t_2 - t_1)$. Starting time $t$ from time $t_1$ then $t = 0$ at time $t_1$ so $i = C$, hence

$$C = i = I_M \sin wt_1$$

$a$ = gradient of the line

$$= \frac{-(I_M \sin wt_1 + I_M \sin wt)}{w(t_2 - t_1)}$$

If $b$ = brush width arc, cm.

$m$ = mica thickness arc, cm.

$v_c$ = commutator peripheral speed, cm/sec.

Time of commutation.

$$t_2 - t_1 = \frac{b-m}{v_c}$$

$$\text{so } \alpha = -\frac{(I_M \sin wt_1 + I_M \sin wt_2)}{w\,\frac{b-m}{v_c}}$$

Formula for current during straight line commutation is

$$i = I_M \sin wt_1 - \frac{I_M (\sin wt_1 + \sin wt)}{w\,\frac{b-m}{v_c}} wt$$

The m.m.f. of the coil due to $i$

$$M = \frac{4\pi}{10} I_M T_b \left[ \sin wt_1 - \frac{\sin wt_1 + wt}{\frac{b-m}{v_c}} t \right]$$

If P = permeance of the leakage flux circuit,

Leakage flux $\phi_L = M \times P$

P will consist of 2 slot and 2 overhang permeances $\phi_L = M(2P_s + 2P_o)$

Linkages

$$\mathcal{L} = (2P_s + 2P_o) \frac{4\pi}{10} I_M T_c^2 \left[ \sin wt_1 - \frac{(\sin wt_1 + \sin wt)}{\frac{b-m}{v_c}} t \right]$$

and reactance voltage

$$e_x = \frac{d\mathcal{L}}{dt} \quad 10^{-8}$$

$$e_x = -(2P_s + 2P_o) \frac{4\pi}{10} I_M T_c^2 \frac{\sin wt_1 + \sin wt}{\frac{b-m}{v_c}} 10^{-8} \text{ volts.}$$

### TRANSFORMER VOLTAGE OF COMMUTATION.

The instantaneous voltage induced in the commutating coil due to transformer action—

$$e_c = -\frac{d\phi}{dt} N_c \cos\alpha\ d \frac{[\phi_M \sin(wt_1 + wt_2 - \partial)]}{dt}$$

Where $\phi \cos\alpha$ is proportion of $\phi$ which passes through the coil, angle $\alpha$ the same as explained in earlier section, and $\partial$ is the angle of lag of the flux behind the current $i$ due to hysteresis.

$$e_c = 2\pi f N_c \phi_M \cos\alpha \cos(wt_1 + wt - \partial)\ 10^{-8} \text{ volts.} \quad (2)$$

This is a negative cosine wave having a maximum value of $2\pi f$ Nc $\phi_M \cos \alpha$.

The r.m.s. value will be this maximum value divided by $\sqrt{2}$ and so gives—

$$Ec = 4{\cdot}44\, f\, Nc\, \phi_M \cos \alpha\ 10^{-8} \text{ volts},$$

the formula given in the earlier section on this commutation transformer voltage.

## RESULTANT COMMUTATION VOLTAGE

Having established the two instantaneous voltage equations $e_x$ and $e_c$, it is only necessary to take the sum of these to find the resultant voltage across the coil.

$e_x$ will be maximum when $\frac{de_x}{dt_1} = 0$

and this gives $\cos wt_1 = -\cos(wt_1 + \theta)$ and this occurs when $wt_1 = \frac{\pi}{2} - \frac{\theta}{2}$, $\theta$ being the electrical angle turned through during time of commutation.

Now $e_c$, will be a maximum when $\frac{de_c}{dt_1} = 0$ and this gives $wt_1 + wt - \partial = 0$.

As $wt$, $\partial$, and $1/2\ \theta$ are small angles, the above voltages, $e_x$ and $e_c$ are pratically 90° out of phase.

Now $e_x$ is trying to maintain the current wave so, with reference to that wave, is a positive sine wave, while $e_c$ is a negative cosine wave.

## RESULTAN T VOLTAGE.

$e = e_x + e_c$ (fig. 5b) and from equations (1) and (2) above it is seen that

$e$ is proportional to $\sin wt_1 - \cos wt_1$

and that is, to $-\sqrt{2} \sin\left(wt_1 + \frac{3\pi}{4}\right)$

so the resultant wave will be a sine wave 135° in advance of position $t_1$) the beginning of commutation). *i.e.* maximum value occurs when

$$wt_1 + \frac{3\pi}{4} = \frac{\pi}{2} \text{ or } \frac{3\pi}{2}$$

$$i.e., wt_1 = -\frac{\pi}{4} \text{ or } +\frac{3\pi}{4}$$

Therefore to obtain the worst voltage condition in the short circuit coil it is only necessary to calculate, at the commutating time $wt_1 = 135°$, the values of $e_x$ and $e_c$ and add them.

## PITCH OF ARMATURE COILS

Full pitch armature coils are seldom used for two main reasons.

(1) Both coil side groups in one slot are undergoing commutation at the same time and the mutual inductance causes greater leakage flux and hence a higher reactance voltage of commutation.

(2) The overhang length is longer than a shorter pitch coil and so a saving of copper is made on the latter. Very little effect is made on performance provided the short pitching is not too severe.

This pitching must be watched with reference to the brush width, as short pitching reduces the available arc of commutation.

It is usual to short pitch the coil throw by one slot for even slotting, or, what is perhaps a better selection, use an odd number of slots, and pitch the coil throw to the slot just short of full pitch.

An old number of slots is useful in that it tends to keep the main flux circuit reluctance more constant as the armature rotates than an even number does.

## CARBON BRUSH

The section should be chosen bearing in mind the full current in the brush due to the input current and the commutating currents, and a value of current density should be used which gives an easy rating to the brush.

Maximum values are given by the brush manufacturers to suit the conditions of working and these values should not be exceeded.

The width of the brush should be such that commutation does not take place while the coil is under the pole arc, and this means that the brush arc must not be greater than (the mean winding arc, less the pole arc, less the skew) for I coil per slot.

For 2 coils per slot, the brush arc must not be greater than (the mean winding arc, less the pole arc, less the skew, less one segment arc).

This usually means that the brush width is narrow on this type of machine and, although it reduces the time of commutation and hence keeps the reactance voltage up on that account, it keeps the number of coils undergoing commutation at any instant down, which is much more important.

As these machines usually rotate at fairly high speeds and the brushes require up to 6 lb. per sq. in. or so pressure, there should not be a high co-efficient of friction between brush and commutator, or overheating may result. A comp romise must often be made as the brushes that can best deal with severe voltage conditions sometimes have a fairly high value of $\mu$ and advice from suppliers is recommended.

It is probably unfair to quote wear rates, as conditions can vary so very greatly on different designs and applications, but rates of wear up to 0.001 in. per hour can take place under difficult high speed conditions on continuous running. As it is probably possible to have a brush depth when new of perhaps only 0.4. in. on a small machine, the life of the brush would be only 400 hours. However, as stated before, this type of machine is very seldom used on continuous duty, so that the 400 hours covers a considerable period of time for applications having only intermittent use, and such rates of wear can be acceptable.

## COMMUTATOR CONNECTIONS

The brushgear being usually a fixture in the frame or bracket, it is not possible to make adjustments to the brush position on test as can be done on large machines, so it is essential for the brush position, for best commutating conditions, to be assessed in the design stage. A useful way of checking this is to draw out, preferably on squared paper, the armature winding diagram, keeping the disposition of the slotting and skewing, if any, to some chosen scale.

The two lines forming the commutator are also drawn in at some convenient distance from the core, but the segment separation lines, *i.e.* micas, are not yet put in.

Then, on tracing paper, the poles and brushes are marked in to the same scale and in such positions that the poles lie over the armature core and the brush edge lies on the edge of the commutator, when the tracing paper is placed over the winding diagram. The tracing paper is then moved over the winding diagram till the neutral position is obtained.

If neutral is required, the mica positions are marked in on the commutator in the correct places. If the machine is for a fixed direction of rotation, then some allowance can be made for armature reaction effect by making the commutating position at a small forward angle. To allow for this the commutator leads are connected to the commutator bars which make the selected angle from the neutral, further round in the direction of rotation.

This angle could be as much as 20° (electrical) or more on a heavily loaded, high-speed armature. The tolerance that can be allowed on the exactness of this point might be about ± 6° but on a slow-speed machine, say, about synchronous speed, the forward allowance of lead would be only about 10° and the tolerance much tighter, probably ± 3°.

If brushes on a rocker can be used, the tolerances to which the commutator lead should be set are relaxed but usually the cost of carrying brushes on a rocker is large compared with the simple arrangement of fixed boxes.

A fair amount of tolerance on performance would have to be allowed when such commutator lead tolerances are not possible.

## CONCLUSION

The foregoing are some of the problems met with in the electrical design of a universal motor. There are others, such as iron losses in the armature, leakage reactances, etc., which would need to be treated in a separate article.

## LIST OF SYMBOLS

| | |
|---|---|
| $\varnothing_M$ | Maximum value of main flux. |
| $N_F$ | Total number of turns on field system. |
| $N_P$ | Total number of turns per pole. |
| $N_A$ | Total number of turns on armature. |
| $N_C$ | Number of turns per armature coil. |
| $Z$ | Total number of armature conductors. |
| $L_i$ | Core length (cm.) |
| $a$ | Electrical angle of plane armature cross field to the neutral plane midway between the poles. |
| $f$ | Supply frequency. |
| $f_n$ | Rotational frequency. |
| $k$ | ratio $\frac{f}{f_n}$. |
| $2p$ | Number of poles. |
| $2a$ | Number of armature circuits |
| | Nuumber of coils undergoing commutation under all brushes at any instant. |
| $n$ | Speed, r.p.m. |

# EARTH MOVING MACHINES
And
# THEIR CAPACITIES

By
Mian Abdul Khaliq*

## INTRODUCTION

The movement of earth is a continuous operation from times immemorial. The childsplay of making up and breaking of the earth will perhaps remain the unfulfilled ambition of the man for ever. Thousands and millions of cubic yards of earth are moved all over the world from day to dawn and from one place to another and nobody can say when and where will be end of all these tiresome efforts. In the early days the primitive methods of moving the earth by hand were employed by the man to dig holes and make caves in the hill sides for and protection and shelter from wild animals and weather extremities. Then with the lapse of time the growing needs of the man taught him to invent hand shovels, baskets and moving the earth on wheelbarrows and donkeys. The plow as an earthmoving tool was designed in 1819. The same old instruments of digging and mowing the earth can be seen even today in the less advanced countries. Then a time came when the intelligent brains started devising instrument which could dig the earth with less effort and carry it easily thus curtailing the time tremendously. A mechanically powered excavator was built in 1834 capable to swing from 180° to 270° which were fitted on the rail road trucks. The Crawler type full revoling shovels were developed between 1910. The dragline bucket was developed in 1903 and gasoline engines were first applied to excavators about 1912. Subsequently other machines like tractors, scrapers, dump trucks, graders, etc., were introduced and now a job which used to take years to complete can be finished in months and days. The Panama canal, the Garrison Dam, the Cherry Creek Dam and so many other big works are the living examples of the success of these machines and of their inventors. As the time passes on several improvements and modifications are carried out in these machines such as electric control, automatic lubrications, torque convertors etc., etc. A day will come when perhaps these machines will also be replaced by machines powered by atomic energy and perhaps still further by the energy received from the sun rays.

Attempts have been made in the following pages to introduce the readers with some of the modern machines which are now very successfully working in completing the development projects of this country. An Engineer is expected to know the brief description and working of the machines. He should particularly be able to find out output of every machine with which he is working so that one should know in how much time and with how many machines a particular project can be completed within the scheduled time. In these days of machine age when the life is so fast and the living so dear he should be able to complete his job very economoically and in the least possible time. It is then only that he deserves a little praise for the bit of the service which he has rendered in making his country self sufficient and in bringing it to the same footing of the well advanced countries.

## THE BULLDOZERS

Bulldozers are tractors equipped with a front pusher blade, which can be raised or lowered by hydraulic or cable control. It

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is primarily used for digging and pushing. The bulldozers may be track type or tire type. The main difference between the hydraulic control and cable control dozers is that in the former case the lift rams are carried on the track frames and the blade is operated through levers while in the latter case the hoist is mounted on the radiator guard and the push arms are hinged to brackets bolted to the outside of the track frames and to the bottom of the blade. The wear and tear of cable and its periodic replacement in case of cable control is more though they have faster lift and drop. More lubrication points are present and sheave bushings and clutch and brake linnings need occasional replacement. The blade in this case cannot be forced down by the weight of the tractor so it tends to ride up over hard surface. In the case of hydraulic control the depth of cut can be regulated carefully though in this case also the flexible hose, the pumps, rams and valves need occasional replacement or repair. The blades in both the cases are practically the same having rectangular base and back. The leading edge of the base is a knife of tough hard steel which projects ahead of and below the rest of the blade. The front of the blade is called the mold board and is concave and sloped back. A bulldozer is moved forward and less commonly backward and raising the blade to contact material to cut, spread or transport it. When the dozer is moved forward it digs some of the soil cut by the blade which piles up in front of the blade, and move with it and some of it will drift off the sides forming ridges. Resistance to the machines movement is made up of the power absorbed in cutting and breaking the soil and in friction in the loosened dirt. For the efficient working of the machine it is always wise to move repeatedly in the same path so that the ridges built up in the earlier passes prevent earth from leaving the blade. When spreading material, the blade is held somewhat above the original surface so that the earth can slip under it in a smooth layer. While dozing on a curved path it is always wise to break the curve up into two or more straight lines separated by angles : to pile the earth at the angle points and to make a separate process of pushing it along the next line. The hollows, smoothing off humps can easily be done by blading.

The bulldozers all over the world are very efficiently employed on moving earth, coal, rock, felling trees, uprooting stumps etc. etc. They can be very advantageously used both on the flat and steep grounds. At Taunsa, world renowned Bulldozers D8 of Caterpiller Tractor Company were employed in digging leading cuts for diversion of the River Indus and in moving pitching stone, constructing bunds and excavating canals etc. etc. Cable control dozers were available for these works. The D8 tractors have two Engines *i.e.*, a starting petrol engine (known as donkey engine) and the diesel engine. The blade of this dozer can be adjusted on either side for extra penetration by a few turns on the tilting braces.

Specifications of D8 dozers are given below :—

Starting engine HP = 24-2700 RPM-2 cylinders.

Diesel engine HP = 130-1000 Governed RPM.

Blade length. = 13′-4″

Blade height. = 38$\frac{3}{4}$″

Blade angle maximum to either side = 25°

Cable—Maximum lift above ground = 527/8″

Control—Maximum drop below ground Not limited.

Hydraulic—Maximum lift above ground = 48$\frac{1}{2}$″

Control—Maximum drop below ground = 16$\frac{1}{2}$″

Weight of tractor. = 35630 lbs.

Weight of blade with rear control = 6280 lbs.

Weight of blade with front cable control = 6010 lbs

Size of cable = $\frac{1}{2}$″

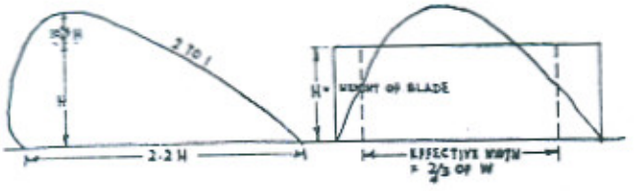
Length of cable for use with front cable control = 40″

Length of cable for use with rear cable control = 60″

Maximum blade tilting arrangement = 12″

Track width = 8′-8″
Overall length = 15′-10″
Overall height = 7′-6″
Rimpull or maximum draw bar pull = 28700 lbs.

*Capacity of a dozer.* The capacity of a dozer depends on the number of cycles it performs in an hour. A complete cycle of a dozer include digging, hauling, dumping, and return, When a blade is set to cut deep the resistance to the machine movement will increase and effect the progress of the machine. If the blade is to cut even depth the resistance to the machine will be less and progress will increase. Similarly output of a machine falls off in almost direct ratio with increase in distance. The progess is also effected by rocky and hard digging *i.e.* by the type of soil. Proper maintenance of the machine and good operation has also a direct bearing on the progress of a machine. The progress of a machine also depends on its size and on the percent of grade. Keeping all these things it is not possible to give definite progress of a dozer. However, attempt is made to find what a Bulldozer can be expected to move on a level grade in average soil conditions. It is assumed that under favourable digging conditions the load carried in front of the blade will be of the shape shown below :—




For Bulldozers we assume that the material will rise 10% higher than the height of the blade.

If H = Heigh of blade.
W = Width of blade.
A = Area (side view)
$L_1$ = Load carried in front of blade.
$L_2$ = Load carried corrected to bank measure.

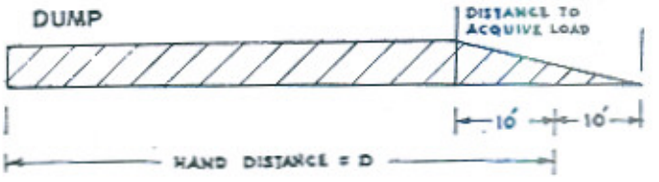
We desire the following formulae :—

$$A = \frac{1{\cdot}1\ H \times 2{\cdot}2\ H}{2} = \frac{2{\cdot}42\ H^2}{2} = 1{\cdot}21\ H^2$$

$$L_1 = \frac{1{\cdot}21\ H^2 \times 2\ W}{3} = \frac{2{\cdot}42\ H^2 W}{3}$$

$$\therefore L_2 = \frac{2{\cdot}42\ H^2 W}{3} \times \frac{3}{4} = {\cdot}6\ H^2 W$$

If we assume that the tractor will be operated in first gear for pushing the load and its highest reverse gear for the return and also that a distance of 20 ft. will be required for the blade to pick up a full load meaning thereby that the Bulldozer actually travel 10 ft. more than the haul distance we can frame capacity tables for all types of Bulldozers.




An output capacity chart for the International Harvester Bulldozers is given for example. Only $L_2$ which is the load carried to the site is calculated in this table and a 50 minutes hour is used for allowing 10 minutes to each hour for miscellaneous work stoppages. Ten seconds is allowed in each cycle for shifting gears.

A comparative specification for wheel and Crawler tractors manufactured by different companies is attached herewith.

It will be noticed that TD 24 of International Harvester and D8 of Catterpiller tally in specifications to a great extent.

The output of a tractor can be found yet in another way. For this purpose the following factors should be taken into consideration in calculating the output of a machine.

1. *Rolling resistance.* It is the sum of the external forces opposing motion over a level ground. It includes the variable effort expended in the action of tracks or tire sidewalls, the compaction or displacement of the roadway over which the unit travels and the resistance due to roughness or unequalties in the road. It includes resistance caused by friction in

wheel bearings by flexing of tires under load and penetration of tires into the ground. The value of rolling resistance for a particular surface can be expressed in lbs. per gross ton of vehicle weight, and approximate values assigned to common haul road conditions. In the case of an average road under big tires at 35 to 50 lbs. air pressure has been evaluated at about 100 lbs. per ton of rolling resistance. A 20 ton machine travelling over this road would require 20 × 100 or 2000 lbs. of rimpull to overcome rolling resistance. A fixed rolling resistance cannot be assigned to a particular type of road as the rolling resistance depends on the tire size, speed and inflation pressure also. However, some general values have been assigned to different types of roads. The value assigned to tire type machines are given above.

| | Type of Haul road surface. | Pounds per ton of gross vehicular weight. |
|---|---|---|
| 1. | Concrete and asphalt. | 30 lbs. |
| 2. | Smooth hard, dry, and gravel, well maintained and free of loose material. | 40 lbs. |
| 3. | Dry dirt and gravel, net firmly packed. | 60 lbs. |
| 4. | Soft unplowed dirt poorly maintained. | 80 lbs. |
| 5. | Wet muddy surface on firm base. | 80 lbs. |
| 6. | Soft plowed dirt or unplowed dirt fulls. | 160 lbs. |
| 7. | Loose sand or gravel. | 200 lbs. |

2. *Grade Resistance.* It is the term applied to opposing force of gravity due to grade. The resistance varies with the angle of grade and weight of machines and is 20 lbs. per gross ton for each 1% adverse grade.

3. *Operators efficiency.* This efficiency varies from man to man day to day and from season to season. Experience has shown that due to unbalanced conditions of hauling and loading units or routing of equipment 83% working efficiency or a 50 minute hour is difficult to maintain for extended period.

4. It has been seen that material having weathered and settled have less voids or air spaces in it and when it is disturbed and loaded it acquires voids and when the material swells. In order to arrive at the pay yard capacity the heaped capacity of a machine is multiplied by the swell factor. Swell factors and weight of various materials is given in the following table.

***Rimpull or trackpull.*** It is the pulling force that the engine can deliver to the tires or tracks at the point of contact with the ground.

$$\text{Rimpull} = \frac{\text{HP} \times 375 \times \text{Efficiency}}{\text{MPH}}$$

HP = Belt horse power.

Efficiency of the engine if unknown accurately can be estimated as 75% to 80%, MPH is speed in miles per hour in different gears.

**Approximate output capacity of Bulldozers.**
*(Cubic yards per hours)*

| Hand D Distance in feet. | T.D. 6 | T.D. 9 | T.D. 14 | T.D. 18 | T.D. 24 |
|---|---|---|---|---|---|
| 50 | 43 | 68 | 123 | 163 | 285 |
| 100 | 26 | 41 | 74 | 99 | 175 |
| 150 | 18 | 29 | 53 | 70 | 126 |
| 200 | 14 | 22 | 41 | 55 | 99 |
| 250 | 12 | 19 | 34 | 45 | 81 |
| 300 | 10 | 16 | 29 | 38 | 69 |
| 350 | 9 | 14 | 25 | 33 | 60 |
| 400 | 8 | 12 | 22 | 29 | 53 |

*Tractive Efficiency.* It is a decimal factor indicating percentage of the weight on the driving tires and tracks which can be utilized in pulling or pushing effort. Some approximate figures of tractive efficiency on various surfaces are :—

| Surface. | Tractive Efficiency Tires | (%) Tracks |
|---|---|---|
| Dry rough concrete. | 80 to 100 | 45 |
| Dry clay loam. | 50 to 70 | 90 |
| Wet clay loam. | 40 to 50 | 70 |
| Damp sand and gravel. | 30 to 40 | 35 |
| Loose dry sand. | 20 to 30 | 30 |
| Dry sand. | 20 | 15-35 |
| Ice. | 10 | 10-25 |

7. *Acceleration.* It is a time-consuming factor requiring an excess of rimpull for any given condition over that necessary just to roll the load. If this excess does not exist to overcome the inertia of a machine and its load, the unit will not be able to increase its speed from the low point to high in a given gear. Experience has shown that if an excess of rimpull in the amount of 20 lbs. per ton is available in the top hauling gear, the prime mover will exhibit good performance characteristics.

In computing the time taken by a bulldozer in completing a cycle the following considerations may be taken into account :

1. Fixed time. This time will be practically the same for all types of bulldozers.

| | |
|---|---|
| Load blade. | .25 minutes. |
| Turns. | .50 minutes. |
| Spread. | .25 minutes. |
| Acceleration and shift. | .50 minutes. |
| | 1.5 minutes |

2. The following example will explain the method of calculating the time per empty and loaded haul :

HP = 148

Length of haul = 300 ft.

Blade width = 13′ – 4″

Height = $38\frac{3}{4}$

$L_1 = \frac{2.42\ H^2W}{3}$ Type of material : dry earth. Grade of haul = 5%

$= \frac{2.42 \times (38\frac{3}{4})^2 \times 13^1/_3}{3} = 112$ cft.

& $L_3 = \cdot 6\ H^2W = \cdot 6\ (38\frac{3}{4})^2 \times 13^1/_3 = 85$ cft.

TABLE

| Material | Weight in bank per cyds. | Per cwt of swell | Swell factor | Loose weight per cyds. |
|---|---|---|---|---|
| Clay, dry. | 2300 lbs. | 25% | .80 | 1840 lbs. |
| Clay, wet. | 2800 lbs | 30% | .77 | 2160 lbs. |
| Clay, dense, tough or wet. | 3000 lbs. | 33% | .75 | 2250 lbs. |
| Earth dry. | 2880 lbs. | 25% | .80 | 2240 lbs. |
| Earth, Wet. | 3370 lbs. | 25% | .80 | 2700 lbs. |
| Earth with sand or gravel. | 3100 lbs. | 18% | .85 | 2640 lbs. |
| Earth with rock | 2500 lbs. | | | 1920 lbs. |
| mixture. | 3000 lbs. | 30% | .77 | 2310 lbs. |
| Gravel dry. | 3250 lbs. | 12% | .89 | 2900 lbs. |
| Loam. | 2700 lbs. | 20% | .83 | 2240 lbs. |
| Gravel wet. | 3600 lbs. | 14% | .88 | 3200 lbs. |
| Rock, hard with | | | | |
| blashed. | 4000 lbs. | 50% | .67 | 2680 lbs. |
| Rock and stone | 3240 lbs. | | | 2400 lbs. |
| crushed. | 3920 lbs. | 35% | .74 | 2900 lbs. |
| Coal anthracite. | 2200 lbs. | 35% | .74 | 1630 lbs. |
| Shale or soft | | | | |
| rock. | 3000 lbs. | 33% | .75 | 2250 lbs. |
| Coal bituminous. | 1900 lbs. | 35% | .74 | 1400 lbs. |

So weight of load carried to bank. = 84 cft.
= 3 tons say,
= 3 × 2240 = 6720 lbs. as weight of dry earth per cft = 2240 lbs.

Haul empty 5% grade

Haul loaded 5% grade

Vehicle hauling load take tractors efficiency as = 60%.

$$\therefore \text{ Max. useable rimpull} = \frac{3360 \times 60}{100}$$
$$= 336 \text{ lbs.}$$

assuming that 50% of the gross weight will be carried by drive types. Taking efficiency of tractor as 85% we can find rimpull in all gears from the formula.

$$\text{Rimpull} = \frac{375 \times \text{NP} \times \text{Efficiency.}}{\text{Speed in MPH.}}$$

1st gear (1·7 mph) = 27588 lbs.
2nd gear (2·3 mph) = 39511 lbs.
3rd gear (2·8 mph) = 16848 lbs.
4th gear (3·7 mph) = 12750 lbs.
5th gear (4·8 mph) = 9828 lbs.

Now rimpull required to move 3 ton weight will be.

Rolling resistance
@ 70 lbs/ton = 70 × 3 = 210 lbs.
Acceleration 20 lbs/ton 3 × 20 = 60 lbs.
Grade resistance = 3 × 20 × 5 = 300 lbs.
Total 570 lbs.

Rimpull available in 5th gear is 9828 lbs.

Which is several times more than the required rimpull so the dozer can very easily haul in 5th gear at 4·8 mph.

$$\text{Therefore time.} \frac{\text{Distance in ft.}}{\text{Speed mph} \times 88} = \frac{300}{4{\cdot}8 \times 88}$$
$$= {\cdot}71 \text{ minutes.}$$

3. *Return haul empty.* Since required rimpull is much less than the available rimpull there is no load and the downgrade helps in the quick motion of the dozer so the dozer can very comfortably return in fifth gear at 4·8 miles for hour.

$$\text{Therefore time.} = \frac{300}{4{\cdot}8 \times 88} = {\cdot}71 \text{ minutes.}$$

Total cycle time. 1.5 + ·71 + ·71
= 2·92 minutes.
Say : 3 minutes.

Taking work productive minute in an hour as 50 giving a job efficiency of 83%

$$\text{Trips per 50 minute hour} = \frac{50}{34}$$
$$= 16{\cdot}6 \text{ Say : } 17$$

Pay load per hour. 84 × 17 = 1421 cft.
Work done in 8 hour shift. 1428 × 8
= 11424 cft.

In these calculations weight of dozer blade and its attachments has not been taken into account. Voids etc., have been taken as Nil so no swell factors has been applied. It has been assumed that the dozer will take turn both before loading and after dumping and travel in 5th gear instead of returning in third gear at a speed of 3·7 mph. Allowance for the distance travelled in gathering load has also been neglected. The rolling resistance has been calculated for tire type tractors. It will be more in the case of track type tractors.

*Rate for 1000 cft. earth.*

Delivered cost of one D8 tractor Rs. 17000/-
No. of working hours. = 10000
Interest, taxes insurance. = Nil.

$$\text{Depreciation per hour.} \frac{17000}{10000} = \text{Rs. } 1/11/-$$

Depreciation per 8 hours shift = Rs. 1/11-8
Rs. 11/13/8/- (A) Say :- Rs. 14/-

Working cost of the machine including lubrication fuel, labour supervision, replacement including tyers = Rs. 12/-

Per 8 hours shift. 12 × 8 = Rs. 96 (B)
Total A + B = 96 + 14 = Rs. 110/-

Total outturn in 8 hours shift = 11000 cft.

$$\text{Rate per 1000 cft. of earthwork} = \frac{110}{11}$$
$$= \text{Rs. } 10/-$$

Rate per 1000 cft. undressed earthwork average lead 300 ft. including lift and premimum as per construction schedule of rates (I.B.) = Rs. 13/4/6

Resale value of the machine has not been taken into account.

The outturn of this machine will be much more on shorter hauls.

ive minute in an hour
ciency of 83%
hour = $\frac{50}{34}$
= 16·6 Say : 17
4 × 17 = 1421 cft.
hift. 1428 × 8
= 11424 cft.

veight of dozer blade
has not been taken
tc., have been taken
rs has been applied.
that the dozer will
loading and after
5th gear instead of
at a speed of 3·7
e distance travelled
lso been neglected.
as been calculated
t will be more in
tors.

ractor Rs. 17000/-
= 10000
= Nil.

$\frac{7000}{9000}$ = Rs. 1/11/-

ift = Rs. 1/11-8
) Say :- Rs. 14/-
achine including
ervision, replace-
= Rs. 12/-

= Rs. 96 (B)
110/-

= 11000 cft.

rk = $\frac{110}{11}$
= Rs. 10/-

ssed earthwork
ing lift and pre-
schedule of
= Rs. 13/4/6

hine has not

will be much



## TRACTORS—(*Contd.*)

| Manufacturer. | Model | Maximum Drawbar H.P. | Maximum Belt H. P. | ENGINE: RPM Governed at full load | ENGINE: Piston speed (FPM) | ENGINE: Piston Displacement (Cu-In) | TRACTOR DIMENSIONS: Length (In) | TRACTOR DIMENSIONS: Height less pipes (In) | TRACTOR DIMENSIONS: Width (In) | Ground clearance (In) | Gauges approximate operating weights (Basic tractor) pounds. | | Number of speeds: Forward | Number of speeds: Reverse | Cooling (Gal) | CAPACITIES: Lubricating System: Crankcase (Qts) | CAPACITIES: Lubricating System: Trans Case (Gal) | CAPACITIES: Lubricating System: Final drive case (each) (Qts) | CAPACITIES: Fuel tank (Gal) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| International Harvestor Co. | TD-9 | 41·31 | 48·91 | 1400 | 1283 | 335 | 114 | 66⅜ | 59½ | 75⅛ | 10⅛ | 44"-10617 | 60"-10777 | 5 | 1 | 13 | 11 | 5½ | 1½ | 31 |
| International Harvestor Co. | T-9 | 42·98 | 48·69 | 1400 | 1283 | 335 | 114 | 66⅜ | 59⅛ | 75⅛ | 10½ | 44"-10272 | 60"-10532 | 5 | 1 | 12 | 11 | 5½ | 1½ | 31 |
| Allis-Chalmers MFG Co. | HD-5 | 40 | 50 | 1800 | 1500 | 142 | 124⅛ | 60⅜ | 62⅜ | 78⅜ | 11½ | 44"-10701 | 60"-11431 | 5 | 1 | 3½ | 8 | 5 | 12 | 37 |
| Caterpiller Tractor Co. | D-4 | 43 | 48 | 1400 | 1283 | 350 | 120½ | 69⅜ | 62 | 78 | 11 1/16 | 44"-10370 | 60"-10860 | 5 | 1 | 11 | 15 | 4½ | 7 | 30 |
| The Oliver Corporation. | BD | 39·3 | 46·5 | 1400 | 1050 | 298 | 106 | 64 | 62½ | 71½ | 10½ | 44"-9533 | 52"-9601 | 4 | 2 | 5 | 12 | 9** | × | 23 |
| The Oliver Corporation. | BGS | 39·9 | 46·8 | 1530 | 1084 | 320 | 106 | 64 | 62½ | 71½ | 10½ | 44"-8720 | 52"-8878 | 4 | 2 | 6 | 7 | 9** | × | 23 |
| International Harvestor Co. | TD-6 | 33·78 | 40·29 | 1430 | 1269 | 248 | 104 | 62⅜ | 53 | 63 | 8½ | 40"-7656 | 50"-7762 | 5 | 1 | 10½ | 9 | 4 | 1 | 20 |
| International Harvester Co. | T-6 | 32·92 | 38·96 | 1430 | 1269 | 248 | 104 | 62½ | 53 | 63 | 8½ | 40"-7189 | 50"-7439 | 5 | 1 | 9½ | 9 | 4 | 1 | 20 |
| Caterpillar Tractor Co. | D-2 | 35 | 42 | 1525 | 1271 | 232 | 107½ | 61⅝ | 55⅜ | 65⅜ | 9 | 40"-7345 | 50"-7609 | 5 | 1 | 7½ | 14 | 2 | 4½ | 26 |
| The Oliver Corporation. | AD | 33·1 | 40·66 | 1530 | 1148 | 226 | 101½ | 54 | 58 | 66 | 12 | 42"-7832 | 50"-8073 | 3 | 1 | 5½ | 13 | 8** | × | 18 |
| The Oliver Corporation. | AG-6 | 32·5 | 38·24 | 1530 | 1116 | 226 | 103½ | 54 | 58 | 66 | 12 | 42"-7252 | 50"-7429 | 3 | 1 | 5 | 8 | 8** | × | 18 |
| The Oliver Corporation. | OC-3 | 21·85 | 26·36 | 1700 | 1133 | 132 | 102½ | 50 | 52½ | 70 1/16 | 10¾ | 42"-3860 | 60"-3468 | 3 | 1 | 2½ | 5½ | 2 | ¾ | 12 |
| Deere & Co. | MC | 18·26 | 22·22 | 1650 | 1100 | 101 | 201 | 50½ | — | 67 | 14 | × | 46"-3967 | 4 | 1 | 3¾ | 5 | — | 3½ | 9 |

***= Includes 200 lb. Counterweight, heavy duty roller shields. ϕ = *Operating weight* with 24" track shoes extended track frame cpded at tachments fuel and water is 42409 pour. * = Includes steering case.

THE ACCURACY OF THIS INFORMATION IS NOT GUARANTEED.

Courtesy of International Harvestor Company. Crawler Tractor specifications March 1954.

# TRACTORS

| Manufacturer | Model | Maximum Drawbar H.P. | Maximum Belt H.P. | ENGINE: RPM Governed at full load | ENGINE: Piston speed (R.M.P.) | ENGINE: Piston Displacement (Cu-In) | TRACTOR DIMENSIONS: Length (In) | TRACTOR DIMENSIONS: Height less pipes (In) | TRACTOR DIMENSIONS: Width (In) | TRACTOR DIMENSIONS: Ground clearance (In) | Gauges approximate operating weights (Basic tractor) pounds- | Number of speeds: Forward. | Number of speeds: Reverse. | CAPACITIES: Cooling (Gal) | CAPACITIES: Lubricating system: Crankcase (Qts) | CAPACITIES: Lubricating system: Trans Case (Gal) | CAPACITIES: Lubricating system: Final drive Case (each) (Qts) | CAPACITIES: Fuel tank (Gal) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| International Harvestor Co. | TD-24 | 155 | + | 1400 | 1633 | 1091 | 182¼ | 98 | × 102 | 137/8 | × 80" – — — — | 8 | 8 | 37 | 30 | 50* | 10 | 85 |
| Allis-Chalmers MFG Co. | HD-20 | 124·25 | + | 1700 | 1588 | 660 | 190¾ | 94 1/16 | × 109½ | 16⅛ | × 84"-41295 | 2 | 1 | 15 | 33 | 9¼ | 30 | 120 |
| Caterpiller Tractor Co. | D-8 | 150 | + | 1200 | 1600 | 1246 | 192½ | 86 | × 103⅜ | 10¼ | × 78"-38155 | 5 | 3 | 25 | 34 | 10½ | 20 | 69 |
| Caterpiller Tractor Co. | D-8 (Pusher) | 150 | + | 1200 | 1600 | 1246 | 192½ | 86 | × 103⅜ | 10½ | × 78"-41685 *** | 5 | 3 | 25 | 34 | 10½ | 20 | 69 |
| The Oliver Corporation. | OC-18 | 133 | 149 | 1500 | 1500 | 895 | 167⅓ | 83 1/16 | × 111¾ | 16 7/16 | × 78"-32500 | 4 | 2 | 15½ | 34 | 26* | 16 | 66 |
| International Harvester Co. | TD-18A | 89·29 | 101·93 | 1350 | 1463 | 691 | 158¼ | 79 | × 82¼ | 14 | × 74"-24631 | 6 | 2 | 26 | 26 | 7½ | 5½ | 60 |
| Allis-Chalmers MFG Co. | HD-15A | 109 | 124 | 1600 | 1333 | 426 | 172 1/16 | 83 1/16 | × 96¾ | 14⅜ | × 74"-28118 | 6 | 3 | 11¾ | 20 | 8½ | 22 | 91½ |
| Allis-Chalmers MFO Co. | HD-15 AC | — | + | — | — | 426 | 172 1/16 | 83 1/16 | × 96¾ | 14⅜ | × 74"-28568 | 3 | 2 | 12½ | 20 | 8 | 22 | 91½ |
| Caterpiller Tractor Co. | D-7 | 90 | + | 1000 | 1333 | 831 | 167⅝ | 81¾ | × 97 | 15½ | × 74"-25980 | 5 | 4 | 17 | 22 | 10¼ | 23 | 70 |
| International Harvester Co. | TD-14A | 65·90 | 75·30 | 1400 | 1517 | 460 | 134⅕ | 73⅜ | × 74⅓ | 92¼ 11⅜ | 56"-15868 74"-16934 | 6 | 2 | 19 | 16 | 6 | 3 | 45 |
| Allis-Chalmers MFG Co. | HD-9 | 72 | 84 | 1600 | 1333 | 284 | 150 | 73½ | × 95 1/16 | 13 5/16 | × 74"-19030 | 6 | 3 | 7¼ | 16 | 6½ | 13 | 55 |
| Caterpiller Tractor Co. | D-6 | 66 | 76 | 1400 | 1283 | 525 | 147 7/16 | 75⅜ | 80½ | 94½ | 12½ 49"-17582 74"-17972 | 5 | 4 | 14½ | 22 | 11½ | 10½ NG-11 WG | 48 |
| The Oliver Corporation. | DD | 60·47 | 74·43 | 1300 | 1138 | 474 | 128 | 67 | 69 | 82 | 10 3/16 48"-13340 61"-13905 | 4 | 2 | 10½ | 16 | 13** | × | 30 |
| The Oliver Corporation. | DG | 60·67 | 71·4 | 1300 | 2138 | 529 | 128 | 67 | 69 | 92 | 10 3/16 48"-12726 61"-13186 | 4 | 2 | 10¼ | 12 | 13** | × | 30 |

| Manufacturer. | |
|---|---|
| R. G. LeTourneau, Inc. | |
| International Harvester | |
| Allis-Chalmers | |
| Caterpillar | |
| Oliver | |
| Mississippi | |
| Road Supply | |

| Manufacturer. | Model | Transmission | 1st | 2nd | 3rd | 4th | 5th | 6th | 7th | 8th | Reverse 1st | Reverse 2nd | 3rd | 4th | Approx: List | Approx : List equipped |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R. G. LeTourneau, Inc. | Super C | Tournamatic | 1·61 | 3·69 | 8·38 | 19·23 | | | | | 3·53 | 8·09 | | | Bare Tractor $20,370 | As Dozer $22,865 |
| International | TD 24 | Sliding Gear | 1·6 | 2·0 | 2·4 | 3·1 | 4·0 | 5·2 | 6·1 | 7·8 | 1·6 | 2·0 | 2·4 7th | 3·1 7·7 | 19,779 | 22,879 |
| Harvester | TD 18A | Sliding Gear | 1·7 | 2·2 | 2·7 | 3·5 | 4·6 | 5·7 | | | | | | | 10,967 | 13,467 |
| | TD 14A | Sliding Gear | 1·6 | 2·0 | 2·6 | 3·4 | 4·4 | 5·7 | | | 1·6 | 3·5 | | | 8,215 | 10,453 |
| | TD 9 | Sliding Gear | 1·5 | 2·2 | 3·0 | 3·9 | 5·3 | | | | 1·7 | 3·4 | | | 5,665 | 7,749 |
| | TD 6 | Sliding Gear | 1·5 | 2·2 | 3·1 | 3·8 | 5·4 | | | | 1·7 | | | | 4,268 | 5,988 |
| Allis-Chalmers | HD 20 | 3 Stage Converter | (0-3·0) mph low | | 0·7 | mph | high | 0-5·5 reverse) | | | | | | | 20,360 | 24,151 |
| | HD 15 | Sliding Gear | 1·40 | 2·10 | 3·0 | 3·9 | 4·50 | 5·80 | | | 1·5 | 3·5 | 4·5 | | 13,915 | 17,131 |
| | HD 9 | Sliding Gear | 1·40 | 2·1 | 2·9 | 3·8 | 4·4 | 5·7 | | | 1·6 | 3·5 | 4·4 | | 9,705 | 13,220 |
| | HD 5 | Sliding Gear | 1·5 | 2·4 | 3·3 | 4·0 | 5·5 | | | | 2·0 | | | | 5,606 | 7,555 |
| Caterpillar | D 8 | Sliding Gear | 1·7 | 2·3 | 2·8 | 3·7 | 4·6 | | | | 2·2 | 3·0 | 3·7 | | 16,810 | 19,723 |
| | D 7 | Sliding Gear | 1·4 | 2·2 | 3·2 | 4·6 | 6·0 | | | | 1·6 | 2·6 | 3·8 | 5·4 | 12,477 | 15,021 |
| | D 6 | Sliding Gear | 1·4 | 2·3 | 3·2 | 4·4 | 5·8 | | | | 1·8 | 2·8 | 3·9 | 5·4 | 9,245 | 11,821 |
| | D 4 | Sliding Gear | 1·7 | 2·4 | 3·0 | 3·7 | 5·4 | | | | 1·9 | | | | 5,822 | 6,826 |
| | D 2 | Sliding Gear | 1·7 | 2·5 | 3·0 | 3·6 | 5·1 | | | | 2·1 | | | | 4,387 | 5,160 |
| | DW 10 | Sliding Gear | 2·8 | 4·5 | 7·2 | 11·7 | 18·8 | | | | 2·6 | | | | 13,787 | 18,472 |
| | DW 20 | Sliding Gear | 2·88 | 5·7 | 8·95 | 16·2 | 26·6 | | | | 3·6 | | | | 20,998 | NA |
| Oliver | FDE | Sliding Gear | 1·61 | 2·74 | 3·7 | 5·0 | | | | | 1·6 | 2·8 | | | 15,350 | NA |
| | DG | Sliding Gear | 1·40 | 2·30 | 3·0 | 4·9 | | | | | 1·7 | 3·6 | | | 8,107 | NA |
| | BG | Sliding Gear | 1·8 | 2·6 | 3·4 | 5·4 | | | | | 1·8 | 3·4 | | | 6,451 | NA |
| Mississippi | MRS 190 | Sliding Gear | 3·07 | 5·99 | 11·49 | 20·09 | 27·00 | | | | 3·97 | | | | 24,125 | 26,735 |
| Road Supply | MRS 150 | Sliding Gear | 3·08 | 6·16 | 11·95 | 20·15 | 31·69 | | | | 3,98 | | | | 22,410 | 25,020 |
| | MRS 125 | Sliding Gear | 3·69 | 7·37 | 13·70 | 24·11 | 37·91 | | | | 3·72 | | | | 19,133 | 21,713 |

# COMPARATIVE SPECIFICATIONS TOURNATRACTOR

## WHEEL AND CRAWLER TRACTORS

| Manufacturer. | Model. | Engine Make | B.H.P. | Governed R.P.M. | Approx. Ship. Wt. Bare Tractor | Tires | Rimpull** or Max. Drawbar Pull (Lbs.) | Overall length | Bare tractor overall width | Overall height |
|---|---|---|---|---|---|---|---|---|---|---|
| R. G. Letourneau Inc. | Super C* | GMC-6-71 | 186 | 1800 | 30,000 | (21·00×25) 16 or 29 Ply (18×25) 12 Ply (65") 18 Ply. | 36,800 | 17′ | 10′ 1" | 8′ 10" |
| International | TD-24 | IHC | 148·43 | 1375 | 38,350 | tracks | 38,600 | 15′ 2" | 8′ 6" | 7′ 5" |
| Harvester. | TD-18 | IHC | 101·98 | 1350 | 22,830 | tracks | 22,850 | 13′ 2" | 6′ 10" | 6′ 7" |
| | TD-14A | IHC | 75·3 | 1400 | 16,650 | tracks | 16,090 | 11′ 2" | 6′ 2" | 6′ 1⅞" |
| | TD-9A | IHC | 48·9 | 1400 | 10,711 | tracks | 11,400 | 9′ 6" | 4′ 11½" | 5′ 6" |
| | TD-6 | IHC | 40·29 | 1450 | 7,920 | tracks | 8,130 | 8′ 8" | 4′ 5" | 5′ 2½" |
| Allis-Chalmers. | HD 20 | GM | 175 | 1700 | 41,000 | tracks | 36,900 | 13′ 10¾" | 9′ 1½" | 7′ 10¼" |
| | HD 15 | GM | 124 | 1600 | 27,850 | tracks | 29,400 | 14′ 3" | 8′ ¾" | 7′ 0" |
| | HD 9 | GM | 84 | 1600 | 18,800 | tracks | 19,030 | 12′ 6" | 7′ 11" | 6′ 1⅜" |
| | HD 5 | GM | 50 | 1800 | 10,500 | tracks | 10,084 | 10′ 5" | 5′ 3" | 5′ 1" |
| Caterpillar. | D 8 | Cat. | 148 | 1000 | 35,630 | tracks | 28,700 | 15′ 10" | 8′ 8" | 7′ 6" |
| | D 7 | Cat. | 93 | 1000 | 25,340 | tracks | 21,700 | 13′ 11½" | 8′ 1" | 6′ 9½" |
| | D 6 | Cat. | 76 | 1400 | 17,130 | tracks | 17,000 | 12′ 3" | 7′ 10½" | 6′ 1" |
| | D 4 | Cat. | 48 | 1400 | 10,735 | tracks | 10,600 | 10′ ¼" | 6′ 6" | 5′ 9⅜" |
| | D 2 | Cat. | 38 | 1000 | 6,870 | tracks | 7,559 | 8′ 11⅛" | 4′ 7¾" | 4′ 9⅛" |
| | DW 10 | Cat. | 115 | 1800 | 16,450 | 2(12·00×20)14 2(21·00×25)20 | 15,930 | 15′ 5" | 7′ 8¼" | 6′ 4" |
| | DW 20 | Cat. | 225 | 2000 | 24,000 | 2(14·00×24)20 2(24·00×29)24 | 25,000 | 17′ 11" | 9′ 2" | 10′ 2" |
| Oliver. | FDE | Hercules | 130 | 1300 | 29,300 | tracks | 26,800 | 14′ 2" | 8′ 6¾" | 6′ 11½" |
| | DG | Hercules Gas | 71·4 | 1000 | 12,398 | tracks | 14,582 | 10′ 8" | 5′ 9" | 5′ 6" |
| | BG | Hercules Gas | 50·0 | 1000 | 8,667 | tracks | 7,600 | 8′ 10" | 5′ 2½" | 5′ 4" |
| M.R.S. | 190 | Cummins | 275 | 2108 | 29,000 | (9×20)(21×25)14 | 22,715 | 16′ 2" | 8′ 4" | — |
| | 150 | Cummins | 200 | 2100 | 25,350 | (9×20)(21×25) | 15,670 | 16′ 2" | 8′ | — |
| | 125 | ICH | 125 | 2200 | 23,800 | (8·25×20)(18×25) | 11,054 | 15′ | 8′ | — |

* Tournatractor comparasion based on (21·00×25) 16 ply tires. and should be multiplied by tractive efficiency to secure drawbar pull.

** Tractor drawbars shown are as advertised for bare tractor. Wheel tractor figures are in rimpull

| 6th | 7th | 8th | Reverse 1st | Reverse 2nd | 3rd | 4th | Approx: List | Approx : List equipped |
|---|---|---|---|---|---|---|---|---|
| | | | 3·53 | 8·09 | | | Bare Tractor $20,370 | As Dozer $22,865 |
| 5·2 | 6·1 | 7·8 | 1·6 | 2·0 | 2·4 7th | 3·1 7·7 | 19,779 | 22,879 |
| 5·7 | | | | | | | 10,967 | 13,467 |
| 5·7 | | | 1·6 | 3·5 | | | 8,215 | 10,453 |
| | | | 1·7 | 3·4 | | | 5,665 | 7,749 |
| | | | 1·7 | | | | 4,268 | 5,988 |
| 0-5·5 reverse) | | | | | | | 20,360 | 24,151 |
| 5·80 | | | 1·5 | 3·5 | 4·5 | | 13,915 | 17,131 |
| 5·7 | | | 1·6 | 3·5 | 4·4 | | 9,705 | 13,220 |
| | | | 2·0 | | | | 5,606 | 7,555 |
| | | | 2·2 | 3·0 | 3·7 | | 16,810 | 19,723 |
| | | | 1·6 | 2·6 | 3·8 | 5·4 | 12,477 | 15,021 |
| | | | 1·8 | 2·8 | 3·9 | 5·4 | 9,245 | 11,821 |
| | | | 1·9 | | | | 5,822 | 6,826 |
| | | | 2·1 | | | | 4,387 | 5,160 |
| | | | 2·6 | | | | 13,787 | 18,472 |
| | | | 3·6 | | | | 20,998 | NA |
| | | | 1·6 | 2·8 | | | 15,350 | NA |
| | | | 1·7 | 3·6 | | | 8,107 | NA |
| | | | 1·8 | 3·4 | | | 6,451 | NA |
| | | | 3·97 | | | | 24,125 | 26,735 |
| | | | 3¡98 | | | | 22,410 | 25,020 |
| | | | 3·72 | | | | 19,133 | 21,713 |

# HYDRO ELECTRIC PROJECTS IN WEST PAKISTAN

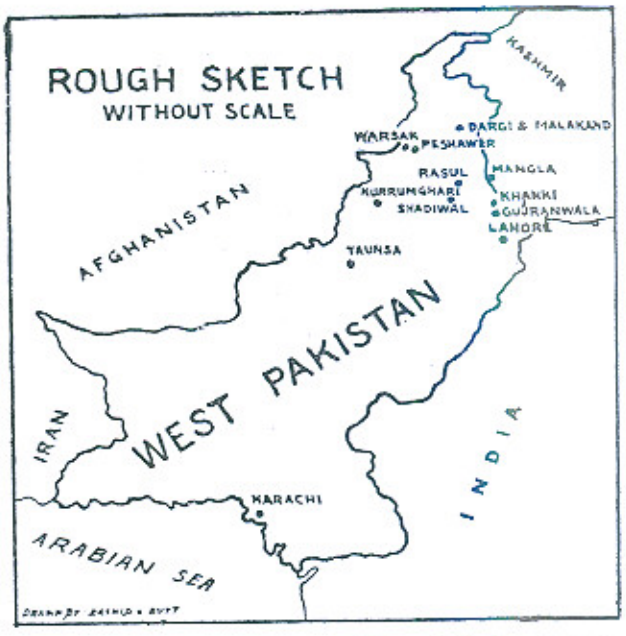
By
M. H. Masud Butt,*

THE system of rivers in the Indus Basin comprises of the main Indus and its two tributaries, the Kabul and the Kurram on the right bank and the Jhelum, the Chenab, the Ravi, the Bias and the Sutlej on the left. The sources of all these rivers emanate from Himalayas, which consist of snow-clad mountains. The portion of the Indus basin which lies in West Pakistan covers an area of 20,400 square miles. The plains of this basin are alluvial in nature. The average rainfall along these mountain tract is beween 28 to 40 inches. This rainfall depends upon the *tricky* monsoons which usually prevail from June to September.

Besides many other factors, West Pakistan is still blessed with large water potential resources, all concentrated in the northern regions. The Indus has a discharge capacity varying from 17.000 cusecs in winter to a peak over 9,00,000 cusecs in summer. The power potential is estimated to be 6,000 Megawatts (M.Ws) from the Indus alone while 2,000 Megawatts are estimated from Jhelum river. Mangla Dam Project has been envisaged to harness 3,00,000 K.Ws. from the Jhelum. As the upper regions of the Chenab are in the occupation of India, it is difficult for Pakistan to assess the power potential of this river. The Ravi, the Bias and the Sutlej could not be harnessed as all possible sites for Hydro-Electric generation lie in India.

Investigations have already been started to find suitable sites for Hydro-Electric Projects on the Swat and Kunhar rivers. Warsak Dam Project is also in an advanced stage on the Kabul river with a generating capacity of 1,60,000 K.Ws. Some of the Irrigation canals in West Pakistan will also generate Electric Power. It has been estimated that 3,00,000 K.Ws. can be made available if these sources are properly tapped. The power potential of West Pakistan is expected to be 93,00,000 K.Ws. which can be summarised as follows :-

*Extra Assistant Director, CEA.




| | | Potential in K.Ws. |
|---|---|---|
| Indus River | ... | 60,00,000 |
| Jhelum river | ... | 20,00,000 |
| Other Tributaries (*viz.* Kabul, Swat and other rivers.) | | 10,00,000 |
| Canal falls | ... | 3,00,000 |

Inspite of this expected forecast of all these rivers of the Indus Basin some sites have already been surveyed and investigated or are now under investigation. It has been estimated that the total yield of the electric energy will be assessed as 35,00,000 K.Ws. in the following way :-

| | | Potential in K.Ws. |
|---|---|---|
| Indus river. | ... | 16,00,000 |
| Jhelum river. | ... | 3,00,000 |
| Other tributaries (*viz.* Kabul, Swat and other rivers) | | 13,00,000 |
| Canal falls | ... | 3,00,000 |

Due to the dire need of electricity to be utilized as a mode of motive power for Industrial, Agricultural and Domestic

reqirements of the Province, many schemes have been designed, implemented and some of them have either been completed or are in progress since the inception of Pakistan. The following list will throw some light on the vital potential assets of West Pakistan under execution :-

| | | Installed capacity in K.Ws. |
|---|---|---|
| 1. | Mangla Dam Project ... | 3,00,000 |
| 2. | Warsak Dam Project ... | 1,60,000 |
| 3. | Gujranwala Hydel ... | 12,000 |
| 4. | Shadiwal Hydel ... | 12,000 |
| 5. | Chichoki Mallian Hydel. ... | 12,000 |
| 6. | Khanki Hydel ... | 9,000 |
| 7. | Kurramghari Hydel ... | 4,000 |
| | Total .. | 5,07,000 |

## POWER DEVELOPMENT

Since the creation of Pakistan many strides have been made. Rasul, Malakand extension and Dargai Hydel Projects have been completed with a capacity of 22,000 K.Ws. 10,000 K.Ws. and 20,000 K.Ws. respectively. The total installed capacity of West Pakistan in 1947 was 20,000 K.Ws. and now it is 1,13,300 K.Ws. an extra 30,000 K.Ws. obtained from the interlinking of some isolated power stations excluding the Hydel and Thermal Power Stations now underway. In view of the rapid industrialization and development in textiles, food products, non-metallic mineral products, leather goods, rubber products, engineering and other allied industries, some Thermal Power Stations have been constructed in the past few years in order to meet this shortage at Lyallpur, Montgomery and Burewala. Another Thermal Power Station with generating capacity of 1,40,000 K.Ws. has been proposed at Multan.

By 1955, the total installed capacity was enhanced by 2,32,000 K.Ws. which is more than three times the installed capacity in 1947. The per capita consumption of energy in 1948 was 1.65 units of public supply undertakings and 1.2 units of private owned plants thus raising the total per capita consumption of power to 2.85 units. In 1955, the total per capita consumption was 10.58 units which comprised of 5.98 units of public supply undertakings and 4.60 units of private owned plants.

Today the West Pakistan Province is in a position not only to meet the internal demand of electric power during the winter shortage period without depending on supplies from India but also is in a position to offer to sell electric energy to India. The achievement of the target by 1960 for West Pakistan is 4,30,000 K.Ws. of electric energy as prescribed by the National Planning Board. However, it is expected that the three Hydel schemes under execution in the Lahore Division at Chichoki Mallian, Shadiwal and Gujranwala will provide 55,000 K.Ws. before 1960 The Kurrum ghari multipurpose scheme was schdeuled for completion by 1959 but according to reports, the work has been delayed due to lack of some essential equipments.

The pace of development would have been even more rapid and many projects would have been put into operation but various bottlenecks have barred the way of this achievement and progress. Non-availability of materials, scarcity in foreign exchange and shortage of technical hands have pushed back the pace of the development. Inspite of all these hurdles and obstacles, a number of Thermal Stations have been commissioned. All this progress cannot fulfil the dire need of the growing public and industrial demands. The Central Govt. appointed Messrs. H. G. Acres of Canada as Consultant Engineers to forecast the census of load demand in various places of West Pakistan. After a thorough investigation of various phases in different sectors of industrial and agricultural dovelopments, a report has been submitted by this Organisation which is under examination and scrutiny by the Government. It has been estimated in the Schedule of Generating capacity that the following additions should be made in order to meet the shortage of Province in the following years :

| | K. Ws. |
|---|---|
| 1955-56 ... | 45,000 |
| 1956-57 ... | 1,55,000 |
| 1957-58 ... | 1,91,500 |
| 1958-59 ... | 1,68,000 |
| 1959-60 ... | 15,000 |
| Total : - | 5,75,000 |

All these estimates need further scrutiny and thorough examination according to the changes made in the Five-Year Plan and some schemes proposed from time to time for various vital industries *viz.* textiles, cement plants, fertilizer factories metallurgical installations, sugar mills, agricultural demands for irrigation and reclamation of land along with the demand of domestic and commercial loads. However, it has been indicated in the First Five-Year Plan 1955-60 that power requirements may rise from 2,20,000 K.Ws. in 1955 to 4,95,00 K.Ws. by 1960.

## SOME HYDEL SCHEMES UNDER CONSTRUCTION

1. **Warsak Dam Project** :—This aims at generating 1,60,000 K.Ws. on the Kabul river at Warsak which is situated 18 miles north-west of Peshawar. The electric energy will be transmitted on double circuit towers at 132 K.V. and will be connected to feed the Main Grid. When Warsak scheme will be commissioned, it will irrigate over 1,10,000 acres of land of the Mohmand and Afridi Tribal areas and also of the Peshawar District. Moreover, the electric power will facilitate the Kohat Valley Tube Well Irrigation Scheme and also supply power to Mulagori Marble mines, coal deposits of Cherat hills, copper ore in Mohmand territory of Kohat District and many other small and large industries. Construction was started in 1948 and a lot of progress has been achieved. It is expected that with the help of Govt. of Canada under Columbo Plan the project will come into force well before the scheduled time.

2. **Mangla Dam Project** :—This envisages to irrigate a vast area and will also provide water further whenever the need will arise. In order to meet this shortage it is expected that the gross capactiy of the Reservior will be further increased. It has, now, been designed to have a live storage capacity of 3.5 million acre feet. This scheme will also generate 3,00,000 K.Ws. of electric power which will be interlinked with the extra high tension grid of West Pakistan on 220 K.V. double circuit towers thus providing a lot of power to meet the vital demand of industrial progress of this part of the Province.

3. **Kurrum Ghari Hydel Project** :—This is being constructed on Baran Nallah which will provide irrigation facilities to total area of 2,62,000 acres and will generate 4,000 K.Ws. of electric pewer. This Hydel station has recently been completed and it is expected to be superimposed on the Main Grid at a later stage. The total cost of the scheme has been estimated at Rs. 45 million.

4. **Gujranwala Hydel Project** :—This has been planned to harness power from Upper Chenab canal at a distance of three miles from Gujranwala town at an estimated cost of Rs. 18 million which will generate 12,000 K.Ws. This electric energy will be utilised for anti-water logging measures and also for Tube Well irrigation purposes.

5. **Shadiwal Hydel Project** :—This has been designed on the Upper Chenab canal near the village of Shadiwal in Gujrat Distt. There are two falls on this canal which will generate 12,000 K.Ws. This scheme will be constructed at an estimated cost of Rs. 10.1 million.

6. **Khanki Hydel Project** :—Lies on the main head regulator of Khanki Head Works on the Lower Chenab canal. It will generate 57.03 million untis. The estimated cost of the Project is expected to be Rs. 12 million. This Hydel station will be connected with the Main Grid at Shadiwal providing more power to meet the need of this part of the Province.

7. **Future Prospects** :—The Govt. of Pakistan have been receiving economic assistance from the Commonwealth countries since 1951 under Columbo Plan. Canada, Australia and Newzealand have offered aid for some Hydel projects for West Pakistan. Besides this some member countries of Commonwealth have provided training facilites under the Technical Cooperation Scheme of Columbo Plan for training personnels to tackle these projects efficiently. I.C.A., U.N. Ford Foundation and other such Organisations have also joined their hands in the execution of various Hydel and other projects directly or indirectly.

In order to achieve the target of 1960 for West Pakistan more efforts towards the attainment of self-satisfaction in electric power will have to be made. It can be

achieved well in time provided more facilities are available for the procurement of materials and *properly placing right persons on the right jobs.* Inspite of all these difficultics Pakistan is marching ahead with her Hydro-Electric Projects.

Future prospects of Hydel projects in West Pakistan are not limited because many sources have to be tapped in future and when the Second Five-Year Plan will be ready the efforts made to examine thoroughly the upper regions of the Province would have matured. With the co-operation of International Organisations and with the help of a team of experts all these water potentials of the existing canals can further be utilised, the Swat river can be tapped, the Indus and the Chenab can further be harnessed to generate hydro-electric power. Small rivers in the north region and heavy rush of flow of water during the rainy season can be utilised for various irrigation purposes and also tapping electric energy. Small rivers in the upper regions and those flowing in the Indus Basin can further be utilised to generate electric-power. However, a lot has yet to be achieved although the progress made during the eleven years need further impetus.

# LARGEST-EARTH-FILLED DAM IN SOUTH AMERICA

THE construction of Venezuela's Guarico Dam, the largest earth-filled dam in South America, has a gigantic earth-filled embankment nine miles long and utilizes the placement of 14 million cubic yards of borrowed earth.

This man-made attempt to improve nature by artificial means, utilizing the Guarico River, combines American and Venezuelan engineering talent to produce a 20th Century miracle. The total irrigation system when completed is estimated to increase the area's agricultural production by over 500 per cent.

Such a project is only one of the many being carried out under the Public Works programme directed by President Marcos Perez Jimenez. His administration has long realized the necessity of diverting the national economy from preponderance of dependence on oil toward agricultural development programmes of this kind.

The huge plains which stretch across the country from behind the mountain-fringed coast provide about 2,60,000 square miles of grazing land, an area comparable in size to England and France combined. But it is subject to seasonal weather that leaves them either flooded or parched. To correct this condition the Guarico Dam was constructed at Galabozo.

The dam consists of an earth embankment nine miles long, extending north and south, with concrete spillway. The embankment varies from 557 to 656 feet wide. The maximum height at its southern end is 98 feet. It will store 460 billion gallons of water in an area of 55,600 acres.

The cost of such a project will come to about 16 million, a matter-of-fact sum in a land where construction projects run to astronomical figures. It is partly financed by the U.S. Export-Import Bank.

Although an army of about 2,500 men was employed on the complete project, only 800 were detailed to the excavation. The job called for two ten hour shifts from 5 a.m. to 1.30 a.m. and an average of 1,00,000 cubic yards were moved every 24 hours.

With the site cleared aided by All is-Chalmers HD.21 tractors, the diversion of the river from its natural bed was accomplished by means of a false channel to leave bare an area 820 feet wide across the river-bed where the structure required special basic work. With this completed, the exploitation of the gravels of the river was made easier. These gravels were essential for the construction of the embankment, consisting of roughly 3/5 gravel and 2/5 clay.

To provide the concrete spillway, called for 1,30,000 cu. yds. of concrete placement and 11 million pounds of steel reinforcing frames on rods for the concrete lining. Concrete syphons are used for bringing pounded water into the main irrigation ditch.

# ON ESTABLISHING A CONTROL POINT

By
Mohammad Ashraf,*

IN an ordinary type of construction the control points for the centre lines of walls etc. are established by driving nails in the pegs fixed in the ground. Sometimes brick platforms are constructed with plastered top over which lines are engraved to mark the location of the control point. These control points are quite good when the work is of an ordinary importance and is to be completed in a short time.

In big projects like Warsak where high quality and accuracy is demanded and the work has to take a long time to complete, most accurate and quite stable control stations are required. These control stations are concrete platforms with steel plates about 6" square fixed in the centre of the platform. A very fine mark is punched on the plate which is correct upto 0.005 foot *i.e.* 1/16". The following Figs. will give you a clear cut idea about the control stations and Triangulation stations.

The co-ordinates of the control stations are known first and then these are established with the help of Triangulation Station. Control Stations usually control the centre line of tunnels, penstocks and other important lines of the Project.

Before we start discussing the control Station we must know a bit about Triangulation Stations as the former are established with the help of the latter.

Triangulation Stations control the arbitrary grid of the whole project and these were established with the regular method of the Triangulation which possesses the following essential features :—

(*i*) The selection of the stations to form a system of connected triangles.

(*ii*) The measurement of one of the sides, known as "base line".

(*iii*) The observation of the horizontal angles and their adjustments.

As soon as the Triangulation Stations were established a detailed survey was carried out and then the major features of the Project were tied into the grid.

Triangulation Stations are established first and then their co-ordinates are calculated after the triangulation but in the case of Control Station its co-ordinates are known first and then these are established. Triangulation Stations control the grid but the Control Stations are tied in a particular part of the Project such as Main Dam, Power House and Irrigation Tunnel.

Establishing a control point requires the following steps :—

(*i*) Location of Control Station on the working drawing.

(*ii*) Selection of suitable Triangulation Stations to establish control point.

(*iii*) Thorough knowledge of the triangulation and the instrument.

(*iv*) Construction of Control Station and the location of control point on the Steel Plate.

(*v*) Rechecking the control point by Triangulation.

## I. Location of Control Station on the Working Drawing.

As soon as the construction engineer gets the working drawing, his first job is to locate the control points on the drawing after a thorough study of the drawing and site.

(Sketch Power House Stage I attached).

If you have a look at the Power House Stage I drawing, you will realize that the most suitable places for establishing the Control Stations are as shown on the drawing. The reason for selecting two control station on the back line of the Power House at a distance of 80 and 88' from the corners are that they will easily control the

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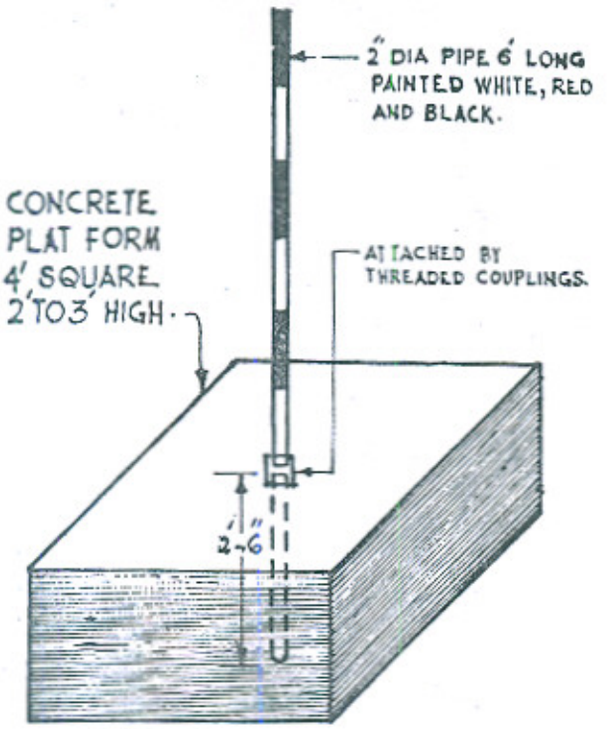



FIG. 1.
TRIANGULATION STATION.

excavation of the back wall and are at quite a safe place. The other two control stations have been selected at the intersection of the end walls and the south edge of the existing road. These two Stations are on the line at a distance of 200 feet from the back wall and the line joining these serve as a Control Line. The existing road is at an elevation 1167 and the interior portion has to be brought at elevation 1167, hence these points are also at quite a safe place. After the completion of Stage I excavation we were given Excavation Stage II Drawing which is much more complicated than the previous one.

(Stage II Excavation Drawing attached)

Control Stations are essential for penstocks units and the other important excavation lines of the Power House. Suitable location for Control Stations are marked on the drawing as these control the centre lines of penstocks, centre line of the units, etc. These have been located at such places so that these should be safe from excava tion and heavy traffic of the machinery. With the help of two corner points whose co-ordinates are given, we can calculate the co-ordinates of all these points.

### II. Selection of Suitable Triangulation Stations to Establish the Control Points

The primary requirement for the selection of two Triangulation Stations is that these should make a well conditioned triangle with the third Control Point, which should be such that the distortion produced by errors in measurement will be minimum. It can be shown that a point located by the intersection of two arcs is least displaced by errors in the radii when the arc intersect at 90°. If the three sides of a triangle are equally subject to error, the three angles should approach 90° as nearly as possible *i.e.*, the triangle should be equilatual, and triangles approximately to this form are termed "Well Conditioned". One should always try to avoid triangles having one or two angles less than 30°. Triangulation stations are scattered all over the Project hence we can have an approximate idea of the triangle by plotting the proposed control point on the drawing where all the triangulation stations are plotted.

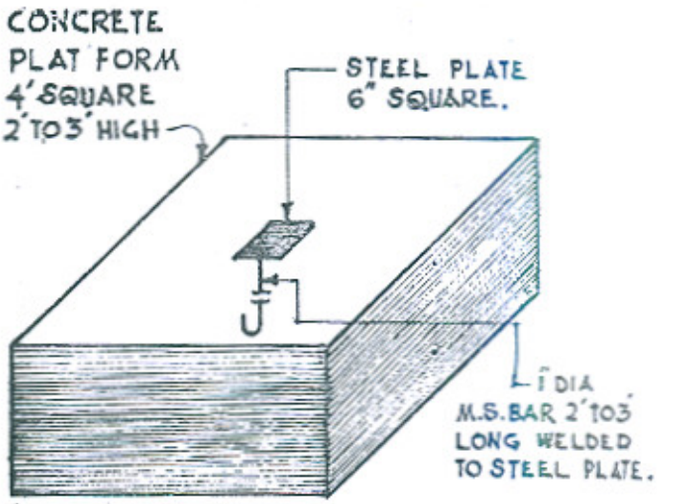
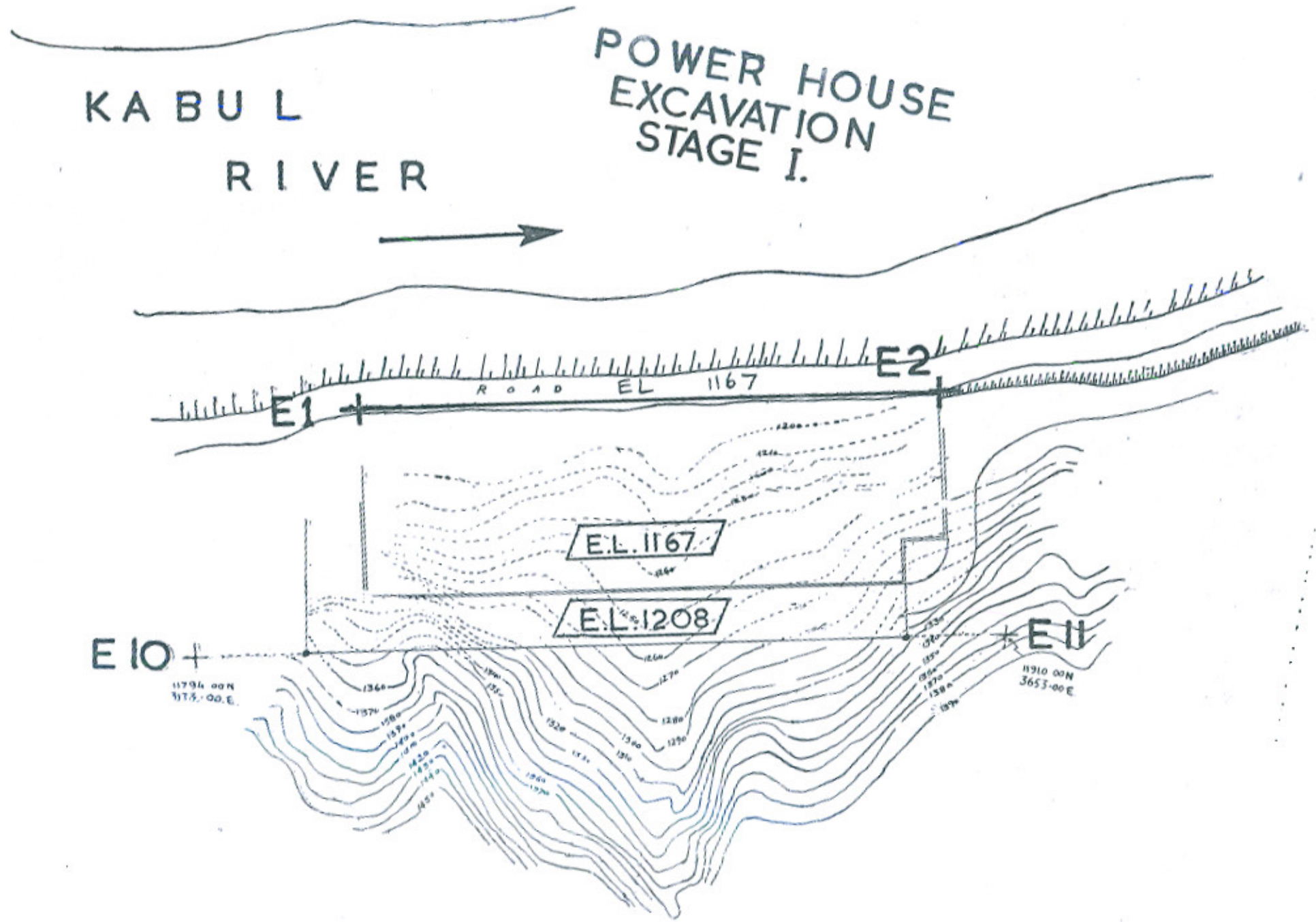


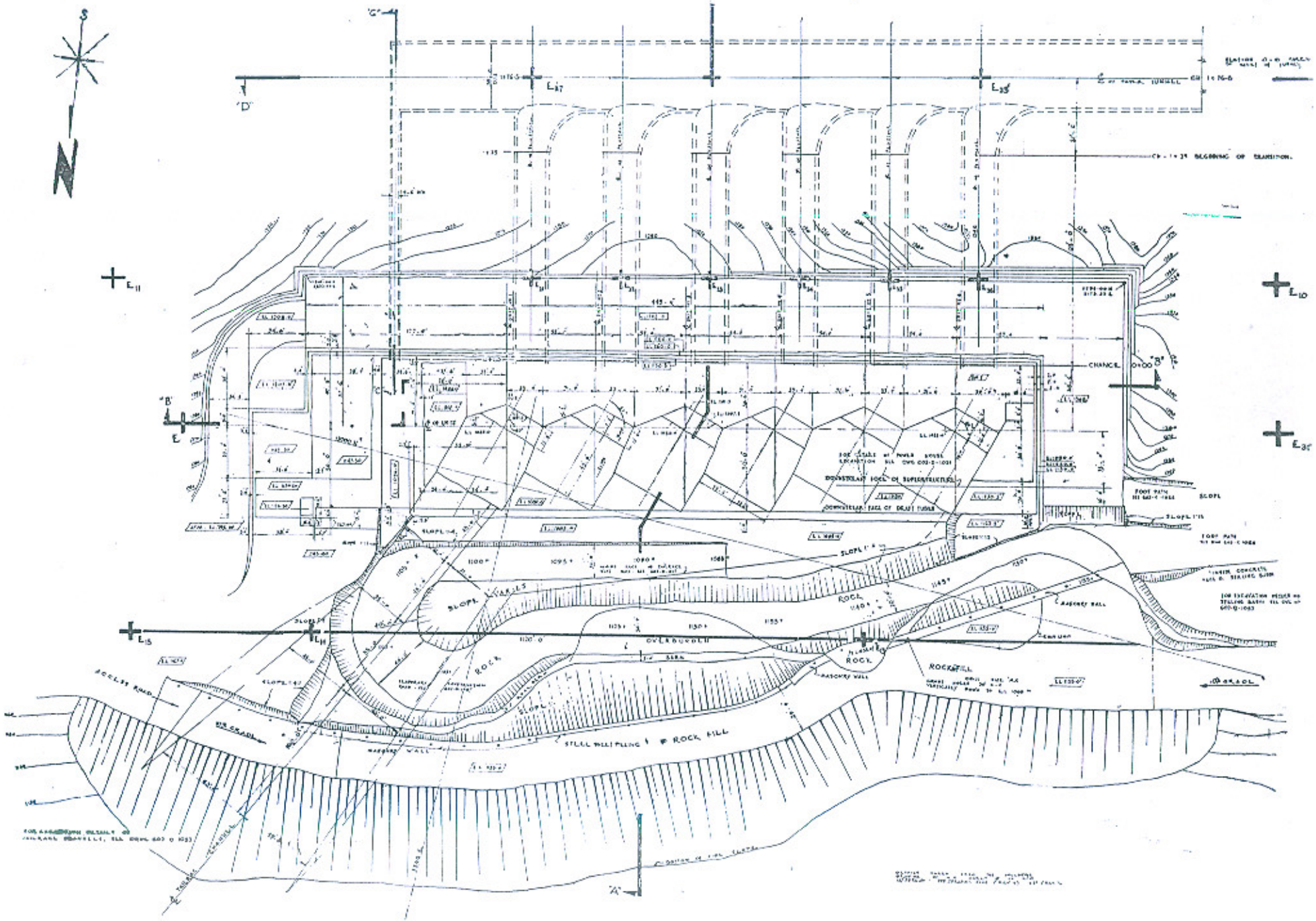

FIG: II
CONTROL STATION.

### III. Thorough Knowledge of the Instrument and the Triangulation

Acres Field Office has got one Watts Microptic No. 2 Theodolite which is considered the most modern and precise instrument as it enables angles to be read to one second of arc and estimated to 1/5th of the second. This is exclusively meant for establishing survey stations and

# POWER HOUSE EXCAVATION STAGE I.




N
'C'
'D'
'B'
'A'
CHANGE
SLOPE
ROCK
ROCKFILL
MASONRY WALL
STEEL SHEET PILING & ROCK FILL
SOCKLEY ROAD
OVERBURDEN
SLOPE 1:4
SLOPE 1:2
SLOPE 1:1.5
SLOPE 1:1.75
SLOPE 1:1.5
SLOPE 1:1.5
SLOPE 1:1.5

the rest of the work is carried out with other Theodolites which are less accurate. The circles in this instrument are both made of glass and the optical micrometer enables readings to be taken direct upto a single second and further to be estimated to fifth of a second. Another special feature of the instrument is an optical plumet which is incorporated in the body of the instrument. The readings on both horizontal and vertical circles are viewed in the same micrometer eye-picce at the side of the telescope though not at the same time. Rotation of a small knob on top of the telescope rotates a prism in the optical system, thus enabling the observer to select the readings of the circle which he wants to observe. This knob has mark H and V to indicate which circle is required.

The Chief sources of error in Theodelites observations are :

(*i*) The instrument is to be checked for permanent adjustments ;

(*a*) Plate level adjustment.
(*b*) Horizontal level adjustment.
(*c*) Line of collimation adjustment.
(*d*) Micrometer adjustment.

(*ii*) Inaccurate centering of the instrument :—This error can be reduced to negligible quantity by care in setting up the instrument and checking the centre through optical plumet before taking every observation.

(*iii*) Error due to instrument being unlevelled :—This error can be avoided by care in levelling the instrument and checking the plate level before each reading.

(*iv*) Error due to imperfect adjustment :—The adjustments of a theodolite are so delicate and depend on so many factors that perfect adjustment in an instrument is practically unattainable. Whenever, you are assigned a job of establishing a Control Station or of triangulation the permanent adjustments of the instruments are checked. The errors due to imperfect adjustment of the instrument may be entirely eliminated by face left and face right reiteration of the required angle. An observation of an angle made with the "face" of the vertical circle on the left of the observer is right. One should take at least 8 readings and the mean of the angles obtained in this way is free from errors of adjustment.

(*v*) Personal Errors are largely due to defective eye-sight or for want of care to focussing the instrument. This error may be reduced in repetition by bringing the cross wires on the object from the left and the right alternately in consecutive observations. If the vision of the observor is defective he must use properly made spectacles.

(*vi*) The Displacement of Signals is probably the most important source of error in angular measurements. In a hilly country where two stations are not at the same level one can only see the top portion of the signal while sighting from the station at a lower level. If the signal is not at right angle to the horizontal plan then we are liable to make mistake as we will shoot the top portion of the signal which is away from the exact position. At a distance of 1000′ a displacement of 1″ will produce an error of 18 seconds which cannot be tolerated in establishing a station where high degree of accuracy is demanded. The remedy to this error is that always shoot the foot of the signal. In case it is not possible then put the signal in vertical position with the plumbob.

(*vii*) Observing under bad atmospheric conditions :—It is waste of both time and labour, accurate work cannot be done in rainy or windy weather. In hot climate the atmosphere is often very unsteady at certain times of the day. This is due to the current of rarefied air rising from the hot ground and objects seen through those uprising currents appear to dance about. It is useless to work under these conditions.

### IV. Construting the Control Station and Establishing the Control Point.

Having in view all the precautionery measures explained above we can go ahead to establish a control point. After the selection of two triangulation stations and the calculations of the co-ordinates for the proposed control point we can find the included angles of the triangle. By setting two Theodolites on the two triangulation stations we can locate the exact position of the Control Station.

(*Continued to Page 42*)

# AIRFIELDS IN PAKISTAN

By

M. M. Tahir*

A large number of airfields were built in Indo-Pakistan Sub-Continent during the last World War II, and a net work of such airfields was spread in the area now comprising West Pakistan and East Pakistan.

When the German armies were advancing in Russia towards Stalingrad, army engineers in India were putting their best efforts to complete the airfields ahead of the schedule time, and contractors were offered bonus for completing their works before the target dates; a few of them did earn the bonus for early completion. The work was, however, suddenly stopped in West Pakistan as soon as the siege of Stalingrad was lifted and the Russians in their turn started pushing the German armies back. By that time, a large number of airfields commencing from the border to the plains had reached completion stage. Work in East Pakistan area, however, continued owing to the threat af Japanese aggression and all the airfields where work was commenced, were finished to completion.

The airfields were built with whatever local materials could be easily procured and incorporated in the work. Some of the airfields were provided with rigid pavements, others were provided with flexible pavements and there were also few airfields which were paved with brick on edge. In some cases, the runways had rigid pavements, while taxi tracks, hardstandings and dispersal pens were paved with bricks. The specifications were generally decided with due consideration to the availability of materials and equipment near the site in order to complete the work quickly. Requirements of site or load of machines that were expected to operate from the airfield were sometimes ignored in preference to the consideration of speed of construction.

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The specifications that were adopted were not different from the conventional specifications of roads prevalent at the time in Indo-Pakistan Sub-Continent. Rigid pavements were laid with 4 inch thick slabs on rolled formation in most cases, while this thickness was increased to 6 inches for the runways that were intended for heavy bombers, and 6 inch to 9 inch bottoming was added as base only in such areas where the bearing capacity of soil was very low.

As regards flexible pavements, 6"/4½" water bound macadam covered with 2 coats of surface dressing on sub-base of 6 inch to 9 inch thick hand packed stone bottoming over prepared base was commonly used over central portions of runways, and rigid pavement on Touchdown areas.

In such localities where water was scarce semi-grouted macadam was substituted for water bound macadam and surface dressing. In certain areas where stone had to be transported from long distances, premixed bitumen carpet was added over hand packed dry bricks on edge sub-base with brick joints filled with dry sand.

In East Pakistan where suitable stone or river shingle is now available only near the Assam border at Chattak in Sylhet District, and was then transported from Orrisa, some of the airfields were with bricks on edge in cement mortar.

After independence, these airfieldes fell to the share of Pakistan Air Force. Most of them were surplus to the requirements of the small airforce that existed at the time of independence. Some of the airfields were handed over to the Civil Aviation Department and are maintained and improved by the said department and used by commercial aircrafts.

These airfields are unfit and unsuitable for the modern aircrafts, not because they were hurriedly built and the workman-

ship or thematerials used in the construction were inferior. The standard of workmanship etc. on these airfields compares favourably to the present peacetime standards, and the pavement of runways and taxi tracks, etc., which have not been extensively used by heavy machines is still in perfectly sound condition but the thickness of pavements in practically all the cases is insufficient to stand the load of the latest type of aircrafts that are now used by the Pakistan or other International Airways, and the need of strengthening the pavements is inescapable if they are to be used by the latest type of aircrafts.

Civil Aviation Department have so far strengthened the pavements of Tej Gaon (Dacca) and Walton (Lahore) Airfield runways out of the many airfields taken over by them from the PAF, and are contemplating to provide a new runway suitable for the heavy aircrafts that are expected to use the international airport at Drigh Road that was originally built for the civil aircrafts.

Tej Gaon (Dacca) runway originally had 2 courses of brick on edge paving laid in cement mortar, and the pavement was in sound condition when it was covered by a thin concrete slab of about 6 inch thickness.

When the work on collecting materials and laying concrete was in progress, the writer was the Garrison Engineer of Dacca Cantt and had watched the progress of the work with keen interest owing to his special interest in airfield works having been associated with the construction of such airfields during the last war. He is associated with the planning and improvement of PAF airfields now, since April 1953.

In 1951 when aggregate for concrete was being collected at Tej Gaon, Railway line to Chattack had not been extended, and facilities for loading ballast at Sylhet Rly. Station existed for a restricted number of wagons. Consequently, it took about one year to collect required quantity of stone and gravel. After the material was collected, the slab was laid on the runway in one working season of 1951-52 (November to April).

The existing pavement was sufficiently strong to offer an unyielding support to the slab under heavy loads, but the base was still not an ideal one. It could not offer a frictionless smooth surface (due to numerous brick joints) on which concrete slab could easily slide on expansion and contraction under variations of temperature or changes of moisture content.

The concrete used was normal mixture (1:2:4) and the best available aggregate and sand was incorporated in the work. The concrete was mixed and laid with sufficient care in small rectangular panels in alternate bays. No expansion joints were provided, or were provided at long intervals inspite of the fact that the concrete was laid in winter.

When the writer visited Dacca early this year, he had noticed that considerable number of rectangular panels in the Touchdown areas had cracked in the centre of the panels. What can be the reason for it?

Army Engineers have also completed a similar runway in 1954 on the existing pavement with 6" concrete slab. The base in this case was 4" thick concrete slab, in Touchdown areas and flexible pavement in the central portion. The contract specification provided minimum strength of 6" test cubes on the 28th day to be not less than 3000 lbs/sq. in and this strength was obtained or rather exceeded except for a few slabs where this strength was not produced, and these slabs were relaid.

The concrete was laid in small rectangular panels of 20' × 15' with expensive and elaborate expansion joints between adjacent slabs. The expansion joints were formed between the adjacent slabs by providing ½" thick and 5" deep flexcell soft boards. manufactured by M/s. Expandite Ltd. of U.K. from molassess and impregnated with bitumen. The boards are highly compressible and regain about 85% of their former thickness when released after being pressed hard. The top 1" depth of the joint is tapered from ½" to 1½" at top and filled with Plastic 99 compound of M/s. Expandite Ltd., to seal the entry of water to the base through the joints of slabs.

The airfield surface before laying new slab was rough and uneven and thus weak concrete was laid before laying new slab to remove unevenness, especially on flexible pavement which has sunk in places.

The top surface of existing concrete slabs were painted with used engine oil before laying new concrete. Still, sympathetic cracks appeared in the new slab in practically the same line where cracks or joints existed in the lower slab. Oiled paper was then placed between the two slabs and this trouble was eliminated.

It was claimed by M/s Expandite Ltd. that Pliastic No. 99 does not melt at less than 180°F and is thus suitable for sealing joints in tropical climates in exposed positions like roads and airfields. The sealing compound however, softened to the consistency of rich cream in hot weather on much lower temperatures and stuck to the wheels of moving aircraft. The matter was referred to the firm and with their assistance the fault was located and rectified in future construction work.

Pliastic 99 is a compound of rubber in bitumen base. The compound was heated in ordinary boilers and taken in ordinary watering cans poured into the joints. When the specified temperature was obtained, fire in the boiler was not reduced and the temperature went on rising during the process of pouring. It ultimately reached a point that rubber content of the compound was fused and lowered the softening point of the compound. On the recommendation of the firm, am obile joint filling machine has now been purchased. The compound is heated in boiler and transferred to pouring machine as soon as required temperature is reached. The temperature of the compound is controlled within a specified range in the machine and the trouble that appeared in the first work hass been eliminated now by the use of mobile pouring maching on other airfield works.

The cracks have however, appeared in a few slabs in Touchdown areas and parking place of heavy aircrafts on this airfield also but they are at the corners of slabs. Why have these cracks appeared? Why are the cracks in this case at different position from Tej Gaon airfield when the strength and thickness of concrets slab as well as the load of aircraft is expected to be the same.

The LCNs (Load Classification Number) have not yet been assessed after test for either of the airfields but they are not expected to be much higher than LCN 15 considering the quality of concrete used, the thickness of slab, and the strong base supporting the slab. Tej Gaon runway is regularly used now by PIA's Superconstellation planes having LCN 45 (approx.) when loaded to full capacity and by the Convairs having LCN 30 (approx). Owing to the wide disparity in LCNs of aircrafts and the airfiled, it is not surprising that failure of slabs has started and deterioration commenced. It would have been more surprising if it had been otherwise.

It is not difficult to assess the LCN of an existitng pavement of airfield and it is essential to test the pavements and find out its actual strength. Take a steel plate of approximately the same area as the contact area of aircraft wheels; 26" dia plate is generally considered suitable for the test. Place the plate at the corner of a conecrete slab and put a lorry over it supported by jack resting in the centre of the plate. Load the lorry increasing the load gradually and noting the readings of load on the said jack. The load at which the slab cracks should be carefully noted. Dividing the load at failure by 1·5 in the case of runways and 2 in the case of parking areas and starting platforms the safe single wheel load on the slab is known. When the safe load is known, the tyre pressure can be worked out by dividing the load wiih the area of the plate. When we know the safe single wheel load and tyre pressure, LCN can be read easily on the standard graphs prepared for the purpose by the Air Ministry (U.K.) and the Institution of Civil Engineers (U.K).

The other question as to why the slabs have cracked at different positions under the same load is still not answered. In Tej Gaon, the cracks are generally in the centre of the panels, while pavement slabs have craked at corners in the other airfield. This must be due to the difference in design of the two pavements. Tej Gaon has none or very few expansion

joints, while the other has numerous expansion joints, and this difference is responsible for the change in behaviour. It is also likely that change of season and temperature at which concreting was done, may also have something to do with the difference in behaviour.

Every small rectangular panel of pavement at Tej Gaon has tried to expand due to rise of temperature in the hot part of the day in summer or the excessive saturation of water after continuous heavy downpour. Owing to the absence of expansion joints, no relief is afforded, and the panel is rather squeezed by similar action in adjoining slabs. As the slab could not expand on the sides, it rose in the centre acting like an arch. The passing of heavy load that could not be supported on the said arch pressed back the slab to its original position which is generally not the weakest point of the slab. This action of load produced crack in the cantre.

These cracks are more numerous in the Touchdown areas especially the starting end than the central position. This shows that the cracks are the result of combined action of loads of aircraft and change in length due to expansion. As the aircrafts generally stop for a few minutes at the starting end, this area is affected more than the central portion where aircrafts pass over different slabs in a few seconds and are partially air-bound while passing over them and the affecting load is considerably reduced.

The crack in the corner of a panel is quite natural under excessive load. As corner is the weakest point in the slab, the effect of heavy load is bound to appear at this point. When travelling load reaches this point, the load transmitted by the wheels does not spread and travel to the next slab owing to the break of continuity, and breaks the corner. Greater the distance between the adjoining slabs, more adverse is the effect of load, and vice versa. The writer considers that the space of $1\frac{1}{2}$" allowed in expansion joints at top surface between two adjoining slabs of the other airfield is excessive. The damage would have been much less if this space had been reduced. It is further established by the fact that the corner of slabs have not cracked at Tej Gaon where butt joints between adjacent slabs exist.

To eliminate the errors that occurred in early stages, the following improvements have been introduced in recent works :—

(*i*) Thickness of slab of pavement has been increased with due consideration of increased load of aircrafts.

(*ii*) Quality of concrete has been improved. Contract conditions previously specified 3000 lbs./sq. inch as crushing strength of test cubes of concrete incorporated in work after 28 days. This has been increased to 3500 lbs./sq. inch in contract specifications and higher flexural strength of concrete is adopted in design.

(*iii*) Design of joints has been considerably improved.

Expansion joints are not kept $1\frac{1}{2}$" wide but reduced to $\frac{3}{4}$" thickness, and spaced at not less than 50'-0" intervals. So far as practicable, square panels are adopted and break joints in expansion joints avoided.

Dummy joints have been introduced between expansion joints. They are spaced at 12'-6" to 15'-0" intervals and are square in panels. In these joints which are about $\frac{3}{8}$" wide, the bottom $\frac{2}{3}$" depth of slab remains continuous, and the opening is made only in top 1/3rd depth of the slab and filled with sealing compound.

Pliastic 99 is still used for sealing but aerolastic compound is used for filling joints in parking areas and starting platform and starting end of Touchdown areas. Aerolastic compound is manufactured with rubber content in Tar Base to safeguard against disintegration of joints by fuel spillage from the Jet Planes. Pliastic 99 is soluble in Jet fuel owing to the bitumen base, while aerolastic is not soluble, as tar is not dissolved in Jet fuel.

Why are dummy joints introduced? The main reason is the reductiou of expansion jointe and reducing the number of corners where continuity in slabs is broken. The number of weak points is then considerably reduced.

There is also another advantage in the introduction of dummy joints. In an exposed slab, the top of concrete slab exposed to sun has a much higher temperature than the insulated base of the slab. The expansion of thick slabs is therefore not uniform throughout its full depth. The expansion is greatest at top and least in the bottom surface in contact with the insulated base. Dummy joints afford sufficient relief to the maximum expansion that occurs at the top surface.

Owing to reduction in depth of slab at the dummy joints, it becomes the weakest line in the slab and cracks if any are expected to occur in this line. The continuity of the slab would still not be broken by crack in this position and the entry of water to the base would be checked by the water seal in the top portion.

The writer had visited Walton Airfield twice when work on the runway was in progress and was pleased to find that the depth of slab had been incrased but its effect was llkely to be minimised due to the use of inferior quality of concrete.

It was proposed to cover the concrete slab with premixed bltumen carpet. This would certainly increase the efficiency and the LCN of the runway, and protect the concrete runway against direct sun and check the entry of water through joints or cracks that may subsequently appear. It would thus increase its life. If ordinay grade of bitumen is used in carpetting, is it likely to give trouble at the starting points if the airfield is used by Jet Planes. Fuel spillage from Jets dissolves and removes bitumen binder from the carpet leaving stone chips separted which fly in the air from blast of exhaust pipes.

When the heated gases from exhaust orifice of Jet Planes which still have their exhaust pipes slightly inclined downwards touch the runway surface, the bitumen or tar binder is likely to melt and the covering carpet may be disintegrated, unless the bitumen used in binder in carpets is specially suitable for such adverse conditions and it is hoped that these aspects were considered before selecting the type of binder for the carpet.

(*Contd. from page 37.*)

Concrete platform is immediately constructed and the steel plate is inserted in the platform at the intersection of two rays from the triangulation stations. The concrete platform is left to set for a day. Next day one instrument man goes to the triangulation station with mic. No. 2 and shoot the lines once with the face of the instrument and then with the face right and then proceed to other triangulation station. Hence we locate the position of the control point by punching a fine point on the Steel Plate.

### V. Checking the Co-ordinates of the Point by Triangulation

To check the accuracy of the control point triangulation is essential. Take eight readings for each angle and the average can be calculated. Now we have to adjust the angles of a triangle or a quadrilateral as the case may be. In case of triangle the only requirement to be satisfied is the summation of the angles to (180°) To obtain the angles required in computing the sides the observed value of each angle is first reduced to $\frac{1}{3}$. The difference between the sum of the resulting angles and 180° is then distributed as equal correction if the observations are of uniform weight or the amounts inversely proportional to the weights if these are unequal.

In case of adjustment of quadrilateral the angles requirements are :—

(*i*) the sum of the observed angles should be 360°.

(*ii*) the opposite angles at the intersection of the diagnals should be equal

$$a + h = d + e$$
$$b + c = f + g$$

(*iii*) The sum of the angles in any of the triangles formed should be 180°

$$\frac{\sin a \sin c \sin e \sin g}{\sin b \sin b \sin f \sin h} = 1$$

Quadrilateral adjustments are more reliable as these satisfy 4 equations. After the adjustment of these angles we can calculate the co-ordinates of the point. This will give the accuracy of the establishment point. In case these are incorrect you can correct it in the fi ld. A final triangulation is carried out to satisfy the result.

Once Control Stations established, we are set to control the particular area of the Project.

# LOW COST HOUSING

By

Khan Muhammad Azam, I.S.E.*

THE cost of house building has gone up considerably. Prices of materials are three to four times of what they were before the last war and labour costs have increased at least 2½ times. The task of providing houses at reasonable cost has become much more difficult. The Engineer is, therefore, put to a greater test today than ever before. The following are few suggestions which may help in keeping the cost of housing down :—

## PLANNING

A little time spent on planning will reduce the plinth area of a house considerably. In this connection keep in view the fact that no spaces should be provided unless absolutely necessary. Make full use of built in cupboards for storage of clothes and belongings. Such cupboards can be from floor to ceiling. The first 6½ feet can be utilized for storing articles of daily use and the space above that for articles used occasionally or empty boxes and trunks. This will avoid having store rooms.

By keeping a long axis of the house East-West and keeping subsidiary rooms on East-West you can save verandahs on these sides. South verandah is a luxury to have and can be avoided in low cost housing. Money spent on making the roof better insulated is more profitable than providing a south verandah with the object of keeping the rooms cool because the roof receives more than three times as much heat from the sun as the south wall does. This is illustrated by Statement

Room width may be kept as small as possible to reduce the section of the battens. Verandahs cost as much as rooms. It might be found economical to have rooms which can be converted at will into verandahs and back into rooms.

*Chief Engineer, Warsak Project.

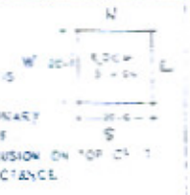
## DESIGN

Foundation should be actually designed avoiding imperical practice and guess work. Greater bearing capacity can be assumed for soils by thorough ramming

THE HEAT GAINS IN A ROOM WHEN SHADED OR WHEN THE SUN RAYS SHINE ON IT DIRECTLY

| NO | DESCRIPTION | | NORTHERN WALL BTU | WESTERN WALL BTU | EASTERN WALL BTU | SOUTHERN WALL BTU | ROOF | TOTAL [illegible] |
|---|---|---|---|---|---|---|---|---|
| 1 | HEAT GAINED DUE TO THE EFFECT OF OUT-SIDE HOT AIR ALONE AT TEMPERATURE OF 105° F IF SHADING IS PROVIDED | | 22,500 BTU | 22,500 BTU | 22,500 BTU | 22,500 BTU | 28,000 BTU | 18,000 |
| 2 | HEAT GAINED DUE TO THE COMBINED EFFECT OF OUT-SIDE HOT AIR AT TEMPERATURE OF 105° AND THE EFFECT OF SUN | | 22,500" | 39,050" | 37,650" | 36,000" | 83,000" | 219,000" |
| 3 | EXTRA HEAT GAINED DUE TO THE SUN RAYS STRICKING THE STRUCTURE | BTU | IN NORTHERN HEMISPHERE SHAPING THE LOCATION | 16,550" | 15,150" | 13,500" | [illegible] | [illegible] |
| | | PERCENTAGE INTENSITY | WALLS DOES NOT HAVE MUCH DIFFERENCE | 77% | 67% | 60% | [illegible] | 85% |
| 4 | SOLAR TEMPERATURE F | | 105 AVERAGE FOR 12 HOURS | 154 AVERAGE FOR 6 HOURS | 152 AVERAGE FOR 6 HOURS | 117 AVERAGE FOR 12 HOURS | [illegible] AVERAGE FOR [illegible] | |

1. ROOM SIZE 20'×20'×8' HIGH EXPOSED ON ALL SIDE
2. TEMPERATURE OF ROOM IN SIDE = 85 F°
   OUT DOOR TEMPERATURE = 105 F°
3. SUN CONDITION OF MONTH OF JUNE ASSUMED WHEN SUN IS AT AN ATTITUDE OF ABOUT 80° AT LAHORE.
4. WALLS ASSUMED TO CONSIST OF 13½" OF BRICK MASONARY THERMAL CONDUCTANCE "U" = 0.312 BTU/HR/F°/IN ROOF ASSUMED TO CONSIST OF 6" OF R.C.C. WITH 4" EARTH CUSION ON TOP OF IT WITH 1½" TILE PLACED ON IT, THE THERMAL CONDUCTANCE (U) = 0.39 BTU/HR/F/IN.




filled according to specifications and by keeping water at optimum moisture and by ensuring that the foundation trenches are properly filled according to specifications and by keeping water away from the foundations as much as possible. Past practice in the Punjab has been to take the bearing capacity of ordinary soils as 0.5 tons per sq.ft. Survey carried out over the Province has shown that higher values of 0.75 to 1 ton/sq.ft. can be safely used.

The foundation masonry need not be in stronger mortar than the wall itself. It is unnecessary to provide off sets to the wall at several stages. Excessive off sets should be avoided and they should

be governed by the angle of disperstion of load.

The conventional damp proof course in vogue *viz.* 3" of 1 : 2 : 4 cement concrete is not damp proof without effective coating of bitumen. The real damp proofing is done by bituminous layer. The cement concrete can be done away with and it would be found economical to provide only a bituminous layer. This can be done by sand-wiching hessian cloth dipped in bitumen between two layer of bricks or using one course of bicks dipped in bitumen.

The common practice of 13½" walls can be replaced by 11" cavity wall with proper 11" bonding bricks after every two stretchers, in every fourth course. These bonding bricks are more effective when they are staggard as shown in plate No. II. Such walls have the same insulation value as 13½" brick walls and are damp proof against continuous wet weather. Further, weight on foundations is reduced considerably. If further insulation is desired the cavity can be filled with inert material like cinder ash, powdered charcoal, glass, wool, etc., etc.

To effect further ecomony in the dry climates of Punjab *ghalafi* work for walls can be resorted to.

PLATE Nº II

11" CAVITY WALL WITH BONDING HEADERS

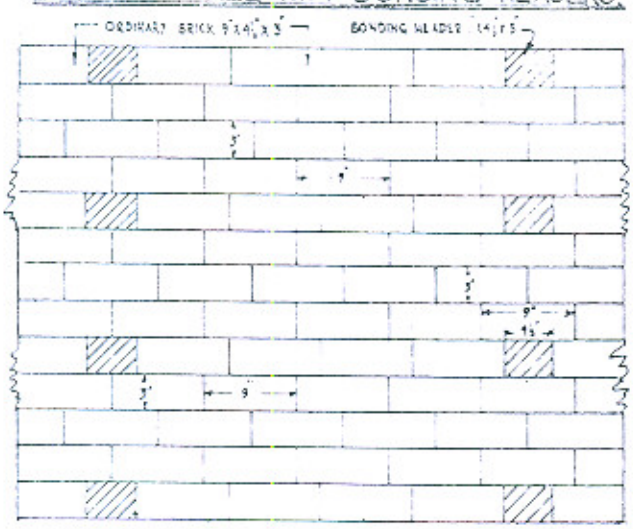



FIG: Nº 4.

In the case of owner occupier of a house there should be no objection against sundried brick walls with mud plaster containing 5% bitumen emulsion. Such a plaster has been found to behave quite satisfactorily against normal rains of Punjab.

Azam's Composite Roof is shown in plate No. III. Design of the roof is such that the brick tiles work as compression flange

PLATE Nº III

AZAM'S COMPOSITE ROOF

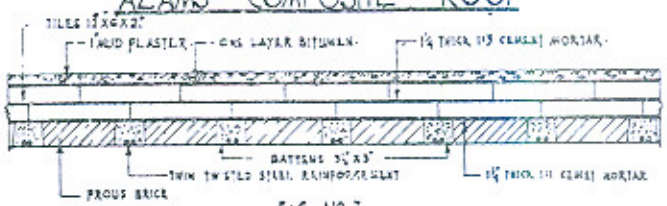



FIG: Nº 3.

of a Tee-beam. The slender precast battens eliminate the necessity of providing work. This roof has many attractive considerations for adoption. It is about the cheapest pucca water proof roof. It is more leak-proof than most of the roofs and is as strong as reinfored concrete slab.

## FLOORING

Plate No. IV shows a fairly cheap type of flooring. It consists of laying bricks flat with bottom dipped in bitumen before laying, over well rammed earth. One inch top of 1:2:4 concrete will make it suitable even for a high class building.

PLATE Nº IV

SUGGESTED CHEAP FLOORS.

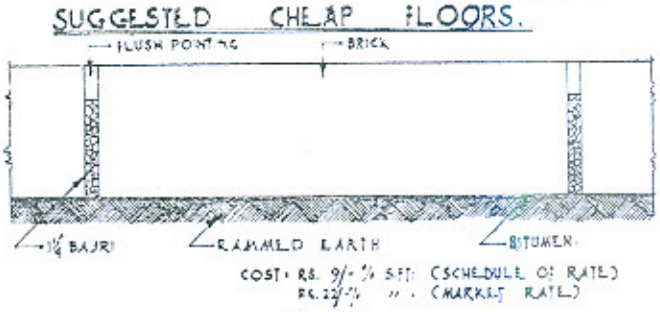



FIG: Nº 1.

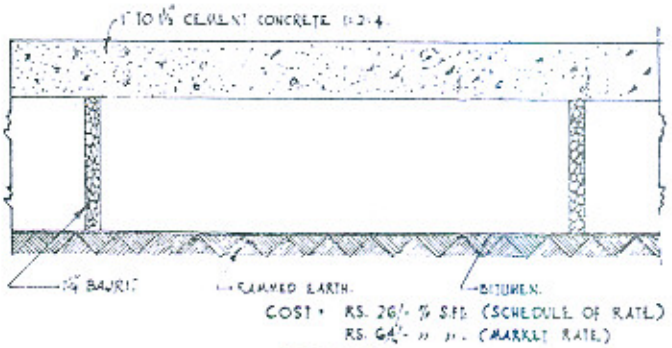



FIG: Nº 2.

## MATERIALS

Use of *surkhi* lime instead of cement sand should be encouraged provided it is cheaper in cost and of correct specifications.

Fine *surkhi* made out of well burnt bricks is very effective as pozzolanic material for portland cement. Replacement upto 30% of cement by such *surkhi* actually improves the quality of cement and as such should be invariably used in place of portland cement. Although slow in initial setting it attains the same strength in 28 days. It resists saltpetre better and is more damp proof. The plaster of such cement has fewer hair cracks than that of portland cement. The pozzolanic cement can even be used in reinforced concrete work. It results in a saving from one to two rupees per bag of cement. Specifications of *surkhi* to serve as pozzolanic material or any other information on the subject can be obtained from the Research Officer, B & R Research Laboratary, Lahore.

The B & R Research Laboratory has developed a porous brick by mixing 5 to 10% of sawdust in the clay from which bricks are made. Such bricks have thermal conductivity co-efficient of about 2.3 as against 4.5 in the ordinary burnt bricks. Its compressive strength, however, is reduced to half of ordinary brick but is still about three times the minimum compressive strength required for brick work. Such a brick has considerable possibilities from the point of view of insulation.

Very few Engineers make use of the well known process of twin twisted steel bars. Bars twisted to a pitch of about 10 diameters have the yield point 50% higher and thus have permissible tensile strength increased by 50%. In Pakistan, the twisted bars have an additional advantage that the re-rolled bars get automatically tested. In this manner the defective steel bars will snap while sound bars will attain 50% extra strength. A saving of 30% in the cost of steel can be effected by this method.

## WOOD WORK

Wood work is about the most expensive item in house construction. Wherever timber can be replaced by either masonry or concrete it should be done. This becomes more important when it is considered that our country is very short of timber.

In this short note I have not attempted to make any suggestions about services and I leave that to someone else more competent to deal with this aspect of house building.

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# BOOK REVIEWS

## DESIGN BY THE LOAD-FACTOR METHOD

"Design of Eccentrically-loaded Columns by the Load-factor Method," by J. D. Bennett (price 8s.). "Tables for the Design of Rectangular Beams and Slabs," by J. S. Cohen (price 4s.). London: Concrete Publications, Ltd.

These concise yet comprehensive brochures have been prepared to simplify the design of reinforced concrete in accordance with the Load-factor method as recommended (for the first time in Great Britain) by British Standard Code No. 114 issued in 1957. Mr. Bennett's work gives twenty charts for the design of columns subjected to direct load and bending about one axis of symmetry, and reinforced symmetrically or unsymmetrically with mild steel and cold-worked bars. Mr. Cohen's tables relate to the design of rectangular beams by the Load-factor method and also by the elastic method, so that it is possible to see at a glance which is the most economical for any particular beam. Worked examples are given with both sets of tables.

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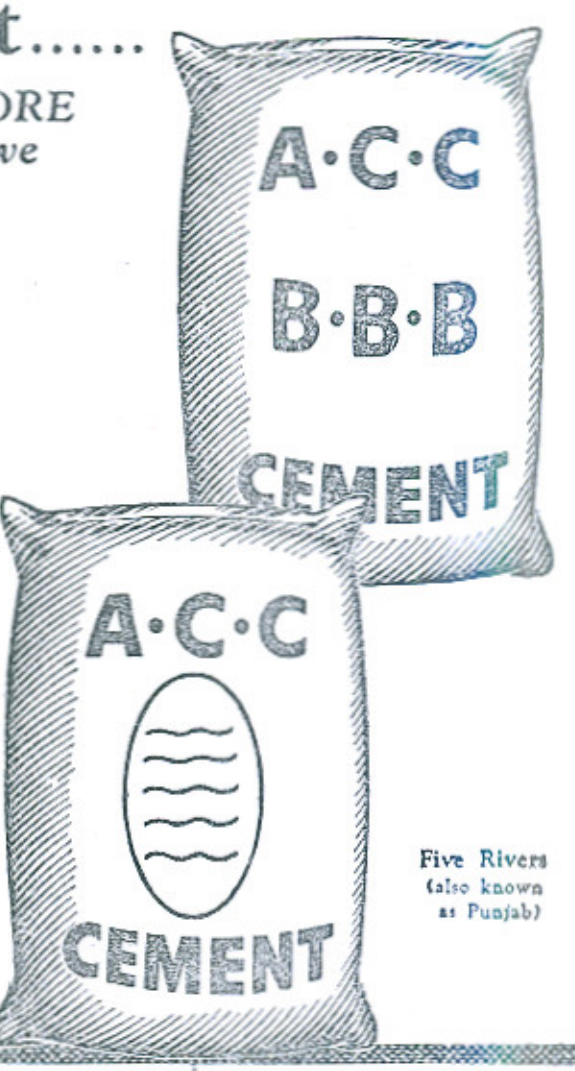


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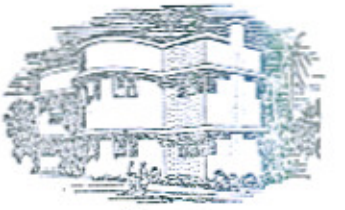

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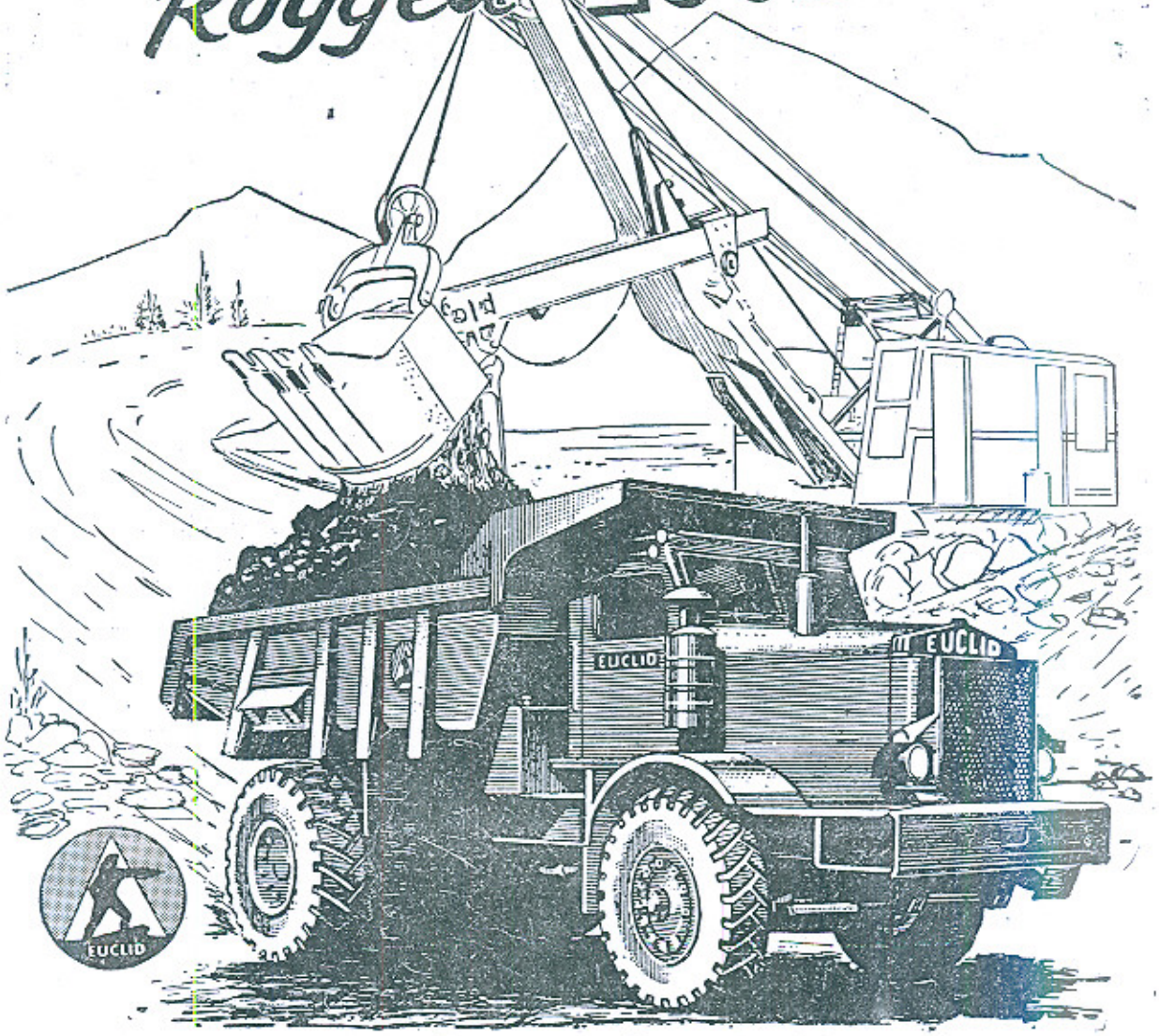


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