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MANUAL LABOUR AND ITS MORE EFFECTIVE USE IN COMPETITION WITH MACHINES FOR EARTHWORK IN THE ECAFE REGION

Report by the Secretariat

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I. INTRODUCTION

The Commission at its tenth session approved the project - Manual labour and its more effective use in competition with machines for earthwork in the ECAFE region - in the programme of work and priorities concerning the Bureau of Flood Control and Water Resources Development.

The importance of the project was fully recognized in the subsequent sessions. It was therefore decided to include this subject for discussion at the Third Regional Technical Conference under the title "Manual labour and its more effective use in competition with machines for earthwork in the ECAFE region".

It will be seen from the paper on "Current programmes for water resources development", presented at this conference, that the countries of the region envisage large development programmes which would involve large quantities of earthwork costing substantial amount of money. Earthwork by manual labour has been in vogue for centuries. With the increase in the size of projects, there has been a growing tendency to use machinery for earthwork partly replacing manual labour. Though there is plenty of manual labour available in the under-developed countries of the region, the use of machinery may be dictated sometimes by considerations of economy and very often by the speed of construction which would yield early benefits and hence quicker returns on the capital invested.

However, for various reasons, as will be discussed later, manual labour will not lose its importance in this region for a considerable time to come.

Although earthwork by manual labour is an ancient art, little or no progress has been made in its technique, whereas mechanized earthwork though of comparatively recent origin has made rapid strides towards improvement in the plant and equipment, and further improvements in the machines are constantly taking place.

/Considering the

Considering the amount of earthwork being done or contemplated under the development plans of the countries in the region, it is felt that the whole question of earthwork should be carefully examined with a view to:

(a) making more effective use of manual labour through improvements in implements, labour incentives, welfare facilities, etc.

(b) determining how far manual labour exclusively, or combination of manual labour and machines, should be adopted.

It will be seen that, in view of the large quantities of earthwork involved, a saving of even a small percentage in the earthwork cost of water resources development projects will ultimately lead to substantial savings.

It may be added that the study has been based mainly on the data collected in Japan as a result of actual observations. It would be interesting to compare it with similar data of manpower required for manual earthwork under different conditions and those of output per hour for different leads for machines like bulldozers, scrapers, etc. derived from observations made in some other countries.

/II. FACTORS

II. FACTORS AFFECTING OUTPUT OF EARTHWORK BY MANUAL LABOUR

A number of factors affect output of earthwork by manual labour. Some of these are detailed below:

A. NATURAL CONDITIONS

Natural conditions like climate and particular weather in which work is done will affect the output. It is well known that output in a cold climate will be much more than that in a warmer climate which renders working conditions for manual labour more difficult.[1/]

Topography and kind of soil will also affect the output. If soil is hard output will be very much lowered as compared to digging in common soil.

B. PHYSICAL CONDITIONS OF LABOURERS

Physical conditions play an important part in output of manual earthwork. The difference can be as much as two times in output due to physical conditions and skill alone. It is well known that labour from certain areas that are habitually used to this type of work can give much better output as compared to an ordinary labourer not so well versed in the art of manual earthwork.

C. IMPLEMENTS USED

Implements should be selected to suit the soil and physical strength of the labourer. The labourer will no doubt use the type of implement he is accustomed to, but its weight and size will need to be adjusted to suit the labourer. The instance, it may be uneconomical to use a small-sized scoop for sand or light soil and similarly to use a small-sized basket for a strong labourer. Means of transportation should be selected having regard to the coefficient of friction and to suit the particular lead and lift involved.

/D. SOCIAL AND

1/ Daily output per excavation of common soil has been reported 150 cu ft/labourer in North India against 75 cu ft/labourer in Bombay area.

D. SOCIAL AND ECONOMIC FACTORS

Factors like wages are important. A well thought out bonus system will of course act as an incentive to increase output. Amenities like hutting, drinking water and labour welfare facilities including recreation and medical facilities have an important bearing on the rate of output. Even apart from advantages of output, greater attention has to be paid to these conditions under the labour laws of various countries.

E. WORKING CONDITIONS

Factors like lead and lift have an important bearing on the rate of output. An executive organization with efficient supervision plays an important part and so does the skill of the foreman in charge of the labour gang.

All the above factors contribute to the total output of the labourers, and, if the aim is to increase the output as far as possible, it would be advisable to give considerable attention to the labour welfare and recreation facilities. Next to the bonus system, which probably acts as the greatest incentive, the contentment and happiness of the worker are the biggest psychological factors contributing to increased output per worker.

/III. FACTORS LIMITING

III. FACTORS LIMITING THE USE OF MANUAL LABOUR

A. NATURE OF EARTHWORK

If the soil to be excavated is very hard, or slush involving under-water work has to be dug, manual labour would find such work difficult, if not impossible, and in any case its efficiency will be very low. Under such conditions machines would be more suitable. An idea of the increase in man-power required to excavate a cubic metre of earth under varying conditions of soil, variation in loading height and under ater excavation may be obtained from the tables given below:

(1) Variation in nature of soil

The increase of manpower required per m^3 for excavation of various kinds of soil, assuming loading height is zero, has been worked out as follows in Japan:

Table 1[1/]

MANPOWER REQUIRED PER M^3 FOR EXCAVATION OF DIFFERENT KINDS OF SOIL

Nature of soil	Manpower required per m^3 (per day)	Ratio
Soft soil	0.084	1.0
Common soil	0.100	1.19
Clay	0.126	1.5
Hard clay	0.166	1.98
Dry hard clay	0.334	3.97

From Table 1, it appears that dry hard clay requires about four times the manpower needed for soft soil.

(2) Variation in loading height

The increase of manpower required per m^3 of excavation and loading with various loading heights, assuming nature of soil as common soil, has similarly been worked out as follows:

/Table 2

1/ Abstracted from "Civil Engineering Construction" by S. Taniguchi, p.55 (Tokyo, Kazama Publishing Co.)

Table 2 1/

MANPOWER REQUIRED PER M^3 FOR DIFFERENT LOADING HEIGHTS FOR COMMON SOIL

Loading height in m	Manpower required (per day) per m^3	Ratio
0	0.10	1.0
0.3	0.102	1.02
0.6	0.104	1.04
0.9	0.108	1.08
1.2	0.114	1.14
1.5	0.126	1.26
1.8	0.148	1.48
2.1	0.204	2.04

From Table 2, it will be seen that, with loading height above one metre, manpower required per m^3 increases rapidly. In case of loading height of 2.1 metres, manpower required is double that at zero loading height.

(3) Underwater work

The increase of manpower required per m^3 for under water excavation, assuming nature of soil is common soil, has been worked out as follows:

Table 3 2/

MANPOWER REQUIRED PER M^3 FOR UNDERWATER EXCAVATION FOR COMMON SOIL

Depth of water in m	Manpower required (per day) per m^3	Ratio
0	0.12	1.0
0.3	0.30	2.5
0.6	0.49	4.1

From Table 3, it will be seen that in the case of underwater excavation of 0.6 metre depth of water manpower required is about four times that at zero. This shows how hard underwater work is for manual labour.

/B. LIMITATION IN

1/ Abstracted from "Civil Engineering Constructions" by S. Taniguchi.

2/ "Standard working rate" Ministry of construction in Japan p.5.

B. LIMITATION IN LEAD AND LIFT

With increases in lead and lift, manpower required per cubic metre of earth increases, with a consequent increase in unit cost. There are physical limitations no doubt apart from considerations of economy. The following tables give an idea of the increase of manpower required with increase in lead and lift.

(1) Manpower required for various leads

Manpower required for the excavation of one cubic metre of common soil in level for different leads has been worked out as follows:

Table 4[1/]

MANPOWER REQUIRED PER M^3 EXCAVATION OF COMMON SOIL FOR DIFFERENT LEADS

Lead m	Manpower required (per day) per m^3	Ratio
30	0.138	1.0
60	0.193	1.4
90	0.248	1.8
120	0.303	2.2

(2) Manpower required for various lifts

The increase in manpower required per m^3 for increasing lifts, assuming that the soil is common and that the lead is 30 m, has been worked out as follows:

Table 5[1/]

MANPOWER REQUIRED PER M^3 OF COMMON SOIL FOR DIFFERENT LIFTS (LEAD 30 M)

Lift m	Manpower required (per day) per m^3	Ratio
0	0.138	1.0
3	0.154	1.12
6	0.204	1.48

/Optimum lead

1/ "Civil Engineering Construction" by S. Taniguchi, p.58.

Optimum lead and lift may be taken as 30 m to 50 m of lead and 3 to 4.5 m of lift, and critical limit of lead should be about 100 m.

As a matter of fact, earthwork by bulldozer would be more economical even for these leads and lifts.

The above data have been collected in Japan as a result of observations over a long period in different parts of the country and may be taken as a good basis for the purpose of this study.

C. TIME FACTOR

Where a large amount of earthwork has to be completed with a maximum of speed, the machine scores heavily over manual labour. A two-yard excavator with about 10 men can do a piece of work in one day which the same number of men will take one month to complete by manual labour. The only way of multiplying output of work by manual labour is to increase the labour force, but a large multi-purpose project imposes its own limitations in regard to the size of the labour force. For example, too large labour force may present difficult problems of housing, sanitation, etc., particularly in the remote localities where such projects are generally located.

The use of machines can sometimes cut down the construction schedule by as much as one half, so that the project will start giving benefits much earlier with a consequent return on the capital invested. If, for example, additional food production to meet shortages in the country is a relevant consideration, the scales may incline sharply in favour of the use of machines.

D. COMPACTION

Experience has shown that compaction by manual labour, apart from being slow and expensive, cannot be as satisfactory as by machines. Compaction involves earthwork in thin layers with optimum moisture to be rolled over sufficiently to give a minimum prescribed dry bulk density. The work of rolling and compaction can be considerably simplified by the use of modern machines, e.g. a tractor pulling a tandem of sheep foot rollers. Where large quantities of earthwork have to be compacted, as in the construction of a dam or high dykes, there is no alternative but to use machines for compaction.

E. SPECIAL PROBLEMS

Mention has already been made in passing of the problems of hutting and sanitation arrangements for a large labour force concentrated in one place. The need to provide greater amenities to labour adds considerably to the cost of the project.

Manual labour has generally to be attracted by heavy financial advances that add to overhead expenses and labourers have to be provided with free transport to the site of work and back. This last difficulty can be overcome to some extent by shifting the labour colony within a reasonable distance of the work-site.

Overhead expenses on manual labour have been evaluated as under:[1/]

1. Hutting charges, providing mats, bamboos, coir ropes, etc. .. 3%
2. Depreciation and mending of tools 1%
3. Transport charges 3%
4. Watchman charges 1%
5. Advances and food arrangements 7%

If lighting, sanitation, water supply, medical services and superior housing are provided, the percentage may rise to such an extent that it may become the critical consideration in the evaluation of over-all economy. Recreation facilities are an additional item which may have to be provided.

/IV. PROBLEMS

1/ Government of India, Ministry of Irrigation and Power, "Report of Construction Plant and Machinery Committee", New Delhi, 1954.

IV. PROBLEMS CONCERNING MECHANIZED EARTHWORK

Mechanization creates its own problems especially in under-employed countries where there is plenty of manpower and general under-employment.

A. MECHANIZATION AND UNDER-EMPLOYMENT

On an average it may be taken that about 17 men operating a machine ($2\frac{1}{2}$ cu yd capacity shovel) can give the same out-turn in ordinary earthwork as 300 men doing manual earthwork in the same period. Even so, on a big project there should be ample scope for engaging manual labour, using machines for the work which is beyond the capacity of human labour. Thus, manual labour can be employed on excavation of canals where leads and lifts are not too high, whereas for the excavation of the dam foundation where space is limited and lifts are high, machines would be more useful. Similarly, for the construction of dykes involving long leads and high lifts, machinery would be more economical after the initial stages of the work. On Nangal power canal in India (part of Bhakra-Nangal Project) work was done both by machines and manual labour. The work involved long leads and high lifts with compaction of banks. Earthwork involved digging of gravel and conglomerate. Out of a total quantity of 7.35 million cu yd of earthwork done, 3.4 million was earthwork of varying hardness; another 3.4 million was gravel and 0.55 million was conglomerate. Of this, 1.6 million cu yd was done by machines and 5.75 million cu yd by manual labour.

This shows how good balance between the work done manual and by machines can be maintained.

B. FOREIGN EXCHANGE INVOLVED IN INITIAL PURCHASE AND COST OF SPARE PARTS

Machines are no doubt expensive and have gone up in price during recent years. In spite of this, it is claimed that in the United States where machines are extensively used, the cost of earthwork in cents per cubic metre has not appreciably increased during the last 40 years though the purchasing power of the dollar is only a fraction of what it was 40 years ago. Still, the fact remains that machines need a good deal of initial investment in foreign exchange which is generally in short supply in the under-developed countries. Spare parts are also an expensive item; though normally projects should not be required to carry their own spares beyond the minimum needed for

/"first line of

"first line of safeguard",[1] and it should be the responsibility of the firms selling the equipment to stock enough spare parts to meet project demands, the average annual requirements of spare parts are of the order of 15 to 20 per cent of the cost of the equipment. This constitutes a considerable drain on limited foreign exchange resources.

C. REPAIRS AND MAINTENANCE COSTS

Maintenance of machines plays a very important part in the economic operation of a project, and a complete and thorough system of preventive maintenance must be established and efficiently maintained. The normal percentage of "sickness" of machines is generally of the order of 25 per cent.

Usually the economic life of a machine such as a bulldozer will be about 10,000 working hours and total expenses on repairs and maintenance during this period (including cost of spare parts) are generally of the order of one to two times the purchase price of the machine depending upon the machine and the conditions under which it is worked. The proportion of maintenance cost will be even higher in the case of low-priced machines like trucks working on poor roads. It will thus be seen how important it is to have efficient maintenance facilities at project sites to prevent breakdown of machines and consequent hold-up of the operations that can sometimes have serious repercussions on the project as a whole. It is therefore necessary to have a well-equipped workshop at the project site with trained mechanics and adequate stocks of essential spare parts.

D. TRAINING OF OPERATORS AND MECHANICS

This raises the question of training of operators and mechanics. In this region there is a shortage of trained technical personnel. Some of the heavy earth-moving machines are new to the countries and need skilled operators. It is necessary that the machines are handled from the very beginning by trained operators who are familiar with the various operations and can handled them efficiently. Similarly, workshops for maintenance should be manned by trained mechanics who can carry out repairs with speed and efficiency. Scarcity of trained mechanics is a serious handicap in any large-scale mechanization of earthwork in this region.

/E. EFFICIENT

1/ Report of Construction Plant and Machinery Committee, 1954, Government of India, Ministry of Irrigation and Power.

L. EFFICIENT MANAGEMENT AND SOUND PLANNING

In mechanized earthwork, expenses for operators and crew form about 10 to 15 per cent of the total operating cost. The principal method to keep the unit cost of earthwork low is obviously to increase the efficiency and productivity of machines. For this purpose, efficient management and sound planning are important.

Plant planning for earth-moving equipment has to be done with great care. The aim should be to have a minimum number of types of equipment with minimum number of sizes in each type making adequate provision for "sickness" of machines (See C above). The temptation to over-mechanize a project should be resisted and efforts should be directed towards ensuring maximum utilization of the equipment.1/ Haul roads should be carefully planned for smooth working, and well maintained in the interest of the machines. Lastly, a realistic figure should be adopted for "productive time" factor.

Before deciding upon the final plan, it will be necessary to work out various alternatives in sufficient detail to study the comparative cost of production and other relevant features of each plan.

A basic requirement of efficient management and sound planning is the maintenance of accurate records of the actual working of each machine. These records are particularly important, and involve the maintenance of daily log-books which should show daily working and maintenance record such as the number of hours worked, output, idle hours, details of minor and major repairs carried out, with parts used and fuel oil and lubricants consumed. In addition, log-books showing the essential data of each machine, major repairs carried out with spare parts used, the history of alterations and cost accounting showing capital cost, cost of alterations and major repairs, depreciation, etc. will need to be maintained. All this calls for good organization.

/V. COMPARISON

1/ A committee appointed in India recently to report on construction plant and equipment on river valley projects recommended that planning should aim at utilizing about 75 per cent the life of the capital equipment (see Government of India Ministry of Irrigation and Power - Report of Construction Plant and Machinery Committee - 1954).

V. COMPARISON OF UNIT OF EARTHWORK

Under similar conditions of work unit cost of earthwork by manual labour will vary with the daily wages of the labourer, as the the daily wages form a very high percentage - 50 to 90 per cent (lower percentage where mechanical means are used for transportation) of the total cost. In order to calculate the unit cost it is necessary to know:

(i) working rate, which means the manpower and material required per cubic metre of earthwork,

(ii) daily wages of labourer.

The working rate will vary in different countries and for different working conditions.

A. WORKING RATE

Assuming net working hours are seven, average manpower required per m^3 will be as shown in Tables 6 to 11.

Table 6[1/]

EXCAVATION AND LOADING BY MANUAL LABOUR MANPOWER REQUIRED PER M^3 (PER DAY)

Kind of soil	Loading height in metres							
	0	0.3	0.6	0.9	1.2	1.5	1.8	2.1
Soft soil	0.084	0.084	0.086	0.09	0.096	0.106	0.126	0.172
Common soil ...	0.10	0.102	0.104	0.108	0.114	0.126	0.148	0.204
Clay	0.126	0.126	0.128	0.134	0.140	0.154	0.180	0.25
Hard clay	0.166	0.168	0.172	0.182	0.196	0.222	0.282	0.500
Dry hard clay	0.334	0.334	0.338	0.344	0.350	0.384	0.454	0.834
Crushed stone	0.112	0.112	0.114	0.118	0.124	0.134	0.152	0.200

/Table 7

1/ Abstracted from "Civil Engineering Construction" by S. Taniguchi, p.55.

Table 7[1/]

EXCAVATION BY MANUAL LABOUR INCLUDING TRANSPORTATION
MANPOWER REQUIRED PER M^3 (PER DAY)

Lead (m)	Lift (m)	Kind of soil					
		Soft soil	Common soil	Clay	Hard clay	Dry hard clay	Crushed stone
30	0	0.129	0.138	0.157	0.179	0.272	0.144
30	3	0.146	0.154	0.175	0.197	0.289	0.161
30	6	0.195	0.204	0.230	0.252	0.344	0.210
60	0	0.184	0.193	0.218	0.280	0.332	0.199
60	3	0.200	0.209	0.235	0.257	0.350	0.216
60	6	0.250	0.259	0.290	0.312	0.405	0.265
90	0	0.239	0.248	0.278	0.300	0.343	0.254
90	3	0.255	0.264	0.296	0.318	0.410	0.271
90	6	0.305	0.314	0.351	0.373	0.465	0.320

Table 8

EXCAVATION BY MANUAL LABOUR AND TRANSPORTED
BY RUBBER TIRE WAGON (CAPACITY 4 cu ft)
MANPOWER REQUIRED PER M^3 (PER DAY)

Kind of soil	Excavation man/m^3	Transportation for lead (m)			
		10	30	50	90
Common soil	0.104	0.032	0.075	0.116	0.214
Hard clay	0.172	0.032	0.075	0.116	0.214

/Table 9

1/ "Civil Engineering Construction" by S. Taniguchi, p.58

Table 9 1/

EXCAVATION BY MANUAL LABOUR AND TRANSPORTED BY NARROW GAUGE TRUCK MANPOWER REQUIRED PER M^3 (PER DAY)

Kind of soil	Excavation man/m^3	Transportation for lead (m)				Total			
		100	200	300	400	100	200	300	400
Common soil	0.104	0.19	0.21	0.23	0.26	0.294	0.314	0.334	0.364
Hard clay	0.172	0.19	0.21	0.23	0.26	0.362	0.382	0.402	0.432

Table 10 1/

EXCAVATION BY MANUAL LABOUR AND TRANSPORTED BY NARROW GAUGE TRUCK ANIMAL DRIVEN MANPOWER REQUIRED PER M^3 (PER DAY)

Kind of soil	Excavation	Transportation for lead (m)					
		100	200	300	400	500	1000
Common soil	0.104	0.026	0.03	0.033	0.037	0.041	0.057
		0.08	0.08	0.08	0.08	0.08	0.10
Hard clay	0.172	0.026	0.03	0.033	0.037	0.041	0.059
		0.10	0.10	0.10	0.10	0.10	0.12

Upper rank is working rate of driver with horse, 2/ lower rank is working rate of labourers engaged on the work.

/Table 11

1/ "Standard Working Rate" Ministry of Construction in Japan, p.14.

2/ Includes effort by horse.

Table 11[1/]

EXCAVATION BY MANUAL LABOUR AND TRANSPORTED BY NARROW GAUGE TRUCK LOCOMOTIVE DRIVEN MANPOWER AND MATERIALS REQUIRED PER 100 M3 (PER DAY)

In the case of common soil:

Lead m	Output per day m^3	Working rate						
		Worker	Operator	Assis-tance	Gasoline (litre)	Mobile Oil(l)	Grease (kg)	Gear-oil (litre)
500	210	21	0.5	0.5	26	0.6	0.11	2
700	189	22	0.5	0.5	29	0.7	0.13	2.3
1000	157	23	0.6	0.6	32	0.8	0.14	2.6
1500	136	24	0.7	0.7	37	0.9	0.15	2.8
2000	126	26	0.8	0.8	48	1.1	0.17	3.0

l = litre

In the case of gravel earth:

Lead m	Output per day m^3	Working rate						
		Worker	Operator	Assis-tance	Gasoline (l)	Mobile Oil(l)	Grease (kg)	Gear-oil (l)
500	200	33	0.5	0.5	26	0.6	0.11	2
700	168	34	0.6	0.6	29	0.7	0.13	2.3
1000	147	35	0.7	0.7	32	0.8	0.14	2.6
1500	126	36	0.8	0.8	37	0.9	0.15	2.8
2000	116	38	0.9	0.9	48	1.1	0.17	3.0

l = litre

/B. MACHINES

1/ "Standard for Design", Ministry of Construction in Japan, p.114-115.

B. MACHINES

As a result of actual observations in Japan over a long period average output is estimated as shown in Table 12, 13 and 14.

Table 12[1/]

AVERAGE OUTPUT PER HOUR FOR A BULLDOZER (15 TONS) FOR DIFFERENT LEADS

Lead m	Output per hour m^3
10	144
20	75
30	55
40	43
50	33
60	275

Table 13[2/]

AVERAGE OUTPUT PER HOUR FOR A SCRAPER (8 CU YD) FOR DIFFERENT LEADS

Lead m	Output per hour m^3
100	64
200	43
300	31
400	23
500	19.2
600	17

/Table 14

1/ "Mechanized Earthwork Construction" by Y. Saito, p.124

2/ "Mechanized Earthwork Construction" by Y. Saito, p.127

Table 14[1]

AVERAGE OUTPUT PER HOUR FOR A POWER SHOVEL (3/4 cu yd)

Kind of work	Output per hour m^3
Easy work	60
Hard work	40

C. COMPARISON OF UNIT COST OF EARTHWORK

Let us compare unit cost of earthwork by manual labour and machines under following conditions:

(a) Net working hours:

7 hours for manual earthwork

6 hours for mechanized earthwork

(b) Kind of soil - Common soil and hard clay

(c) Working rate and output per hour

According to A. and B. above

(d) Cost to include all necessary expenses, such as those for workers, operating expense for machine, repairs, depreciation, transportation and administration.

(e) Assuming wages and prices as:

Manual labour	400 in yen per day	(US$ 1.11)
Operator	800 " "	(" 2.22)
Assistant	500 " "	(" 1.39)
Bulldozer	7,500,000 " for one	("20,833.-)
Scraper with tractor	10,500,000 " "	("29,167.-)
Power shovel	8,200,000 " "	("22,788.-)
Gasoline	40 per litre	(" 1.1)
Mobile oil	150 per litre	(" 4.2)

/Detailed calculations

1/ "Mechanized Earthwork Construction" by Y. Saito, p.129

Detailed calculations for a few typical cases are shown in the Appendix and results have been illustrated in graphs 1, 2 and 3.

These graphs show the unit rates of different types of earthwork to serve as a guide for selecting the most economical unit to suit the particular conditions. Some adjustments will no doubt be necessary to suit actual conditions but the illustrations given will serve as a useful guide and represent average conditions.

/VI. SOME SUGGESTIONS

VI. SOME SUGGESTIONS TO INCREASE THE EFFICIENCY AND REDUCE THE UNIT COST OF MANUAL EARTHWORK

This is the most important problem in earthwork by manual labour. To increase the efficiency means to increase the output per labourer. The output has the following relation in general:

Output per labourer = Q.H.B

where Q = average output per hour per labourer (m^3/hr)

H = average net working hours per day - hrs.

B = number of working days.

A. TO INCREASE THE EFFICIENCY OF MANUAL EARTHWORK

As the total output is Q.H.B, we will have to make Q, H and B bigger in order to increase the output of manual earthwork. In other words, we have to increase the output per day.

(1) How to increase output per day

Output per day = Q.H = q.N.H

where q = quantity of earthwork moved at one time

N = number of transportations per hour

This formula is changed to:

$$q.N.H = q \times \frac{60}{\frac{L}{v} + \frac{L}{v'} + c + d + e} \times H$$

where L = transporting distance .... m

v = average velocity loaded .... m/min

v' = average velocity empty .... m/min

c = time for loading .... min

d = time for unloading .... min

e = time for idling .... min

/Therefore

Therefore, in order to make Q.H. bigger:

Make q bigger : Use of bigger size of implements, loading as much quantity as possible.

Make L smaller : To make L smaller, we have to select borrow pits as close to the work as possible.

Make v, v' bigger: This will be governed by the physical strength of the labourer. Make upward gradient as small as possible. Where possible select proper downward gradient when loaded.

Make c smaller : In order to load as quickly as possible keep excavation depth and loading height as small as possible. Pump out water when doing underwater work, select right implements to suit the soil. For example, choose large size scoop for sand and light soil, spade for clay etc.

Make d, e smaller: Unloading should be done as quickly as possible and unnecessary idle time should be eliminated.

In order to accomplish the above:

(i) Work on downward slope when loaded, make upward gradient as small as possible. For instance, with rubber tire wagon, the output will be 40-50 per cent bigger in level than in case of 1/20 upward gradient.

(ii) Use of animals, if possible. In general a horse and an ox have power 6 to 8 times bigger than the physical strength of a manual worker.

(iii) Select the mode of transportation with minimum resistance. This is very important for transportation by manual labour and animals.

Table 15 shows how the load transported increases with reduction in rolling resistance.

Table 15

LOAD TRANSPORTED UNDER DIFFERENT CONDITIONS

Method of transportation	Load transported per labourer in kg
Carrying on labourer's shoulder	40 - 50
By gum tire wagons	120 -160
By narrow gauge trucks	400

/As for

As for calculations:

(a) On labourer's shoulder:

As a result of actual observation:

A labourer will carry 50 kg in Japan and about 40 kg (one cu ft) in India

(b) Transported by tire wagon, capacity of 4 cu ft (160 kg of earth) will be driven by one labourer:

Weight of wagon	70 kg	
Load of earth	160 kg	(4 cu ft of earth)
Total weight $\bar{W}$ =	230 kg	

Rolling resistance coefficient (λ) may be assumed 0.1 to 0.15 for soft soil, so that necessary tractive force in level is $\bar{W}$ = 23 to 34.5 kg, and necessary tractive force in 1/20 upward gradient is $\bar{W}$ $(\sin\theta + \lambda\cos\theta)$ = 34.4 to 45.9 kg, where θ is angle of gradient (2° 54').

As the limit of the tractive force for a labourer is nearly 45 kg, a labourer will be able to transport 4 cu ft of earth in 1/20 upward gradient.

(c) Transported by narrow gauge truck:

A narrow gauge truck, capacity of 0.6 m^3 (assuming 870 kg of earth) can be pushed by two labourers, or 400 kg by one labourer.

This will be clear from:

Weight of truck	280 kg	
Load of earth	870 kg	(0.6 m^3)
Total weight $\bar{W}$ =	1,150 kg	

Rolling resistance coefficient (λ) may be assumed 0.025

Necessary tractive force in level = 28.6 kg

Necessary tractive force in 1/20 upward gradient will be about 86.25 kg which is less than 90 kg (pushing capacity of two labour[illegible]

/(iv) How to

(iv) How to make N bigger:

Actual factors to make N bigger have been mentioned above. It will depend mainly on the cycle time of the earthwork. In other words, we have to make the cycle time minimum. This will be discussed later.

(v) To make H bigger:

Generally speaking, the components of the time will be preparation, working, rest for lunch, rest period and idleness. In order to make H bigger we must minimize all components other than actual working time. H will be usually from 7 to 7.5 hours, but the main problem is how to eliminate the idle time. This will depend largely upon the way work is organized and on the efforts of foremen etc.

B. IMPLEMENTS

It is very important that the right type of implements are used for excavation. To give an example, large sized scoops should be used for sand and light soil and spades for clay etc. Generally, a trained earthwork labourer will pick up the right type of implements for the particular soil. It has been observed that for damp or wet earthwork, the cutting blade should be smaller (as the earth is heavier), and its angle to the handle more actue, for ease in excavation. For dry earthwork, on the other hand, the cutting blade of the spade should larger forming a bigger angle with the handle.

Where earth is hard, it will be easier to loosen it first by pickage before excavation with a spade. Where lift involved is small, certain types of labour find it easier to carry two baskets suspended from either side of a pole supported on the shoulders than a single basket carried on head or shoulder. Actually, it is a matter of judgment based upon experience to select the right type of implements to suit the soil and the physical condition of the labour. It is for the foreman to take proper interest in these aspects of work in order to secure the maximum efficiency out of the men and material at his disposal.

C. LABOUR WELFARE FACILITIES

Labour welfare facilities play a very important part in the daily output of the labour, combined with wage incentive and bonus system. Improvement in housing conditions, drinking water sanitation arrangements, medical facilities and recreation facilities go a long way in creating conditions conducive to increased output. Combined with wage incentive and bonus system, these secure maximum output under any given conditions.

/It is

It is gratifying to note that in the region, generally wage incentive and bonus system are in vogue, and housing, drinking water, medical and in some cases even recreational facilities are provided to labour.

Labour welfare facilities on the Kosi Project involving construction of flood embankments in India where the labour force at peak was of the order of 60,000 men may be given by way of illustration.

(i) Temporary thatched huts were provided, for housing the imported labour, with a living area at the rate of 25 sq ft per labourer. A labour force of about 1,000 men was estimated to be required per mile of the flood embankment. Provision for hutting was made for 50 per cent of the labour force on the assumption that half the labour force would be from the neighbouring villages and would not need any housing accommodation.

(ii) For drinking water, one tube well (worked by hand) was provided for every 200 labourers, i.e. five tube wells for every mile of the embankment.

(iii) At the headquarters of the Division (charge of an Executive Engineer) there was a medical officer. At the headquarters of the sub-division (charge of an Assistant Engineer) was stationed a compounder. Standard medical boxes were provided every two miles of the embankment. There was embulance at the Divisional headquarters. The entire Division was under the charge of the medical officer who went round the Division for examination of patients and supply of medicines. The area being highly malarial, the anti-malaria wing of the State Government also operated in the project area with the result that malaria was brought under control and incidence of sickness greatly reduced.

(iv) A welfare officer was attached to each division and a welfare inspector to each sub-division. It was their responsibility to see that contractors made due payment to their labour force.

(v) Government kept reserve stocks of rice which was sold to labour at fair price.

(vi) A mobile cinema van was provided for each division. Sometimes one van served two contiguous divisions.

(vii) Community centres were provided. They were supplied with newspapers, and arrangements were made for indoor and outdoor games like volleyball, etc.

/It is estimated

It is estimated that total welfare cost including hutting, light, water supply, medical and recreational facilities came to about Rs 5/ per 1,000 cu ft of earthwork. (Basic rate for earthwork is Rs 17/8/- /oo cu ft)

It is felt that but for these amenities it would not have been possible to collect all the labour force in this remote area, with its unhealthy conditions, and to keep them on the job.

D. HOW TO REDUCE UNIT COST

$$\text{Unit cost} = \frac{\text{Expenditure}}{\text{Total output}}$$

In order to reduce the unit cost, we must economize on expenditure and increase the output as far as possible.

1. To minimize the expenditure

In general, the cost of labour wages as a percentage of total cost of earthwork by manual labour may be taken as given in the table below:

Table 16

COST OF LABOURER'S WAGES AS PERCENTAGE OF COST OF EARTHWORK BY MANUAL LABOUR

Kind of work	Labour wage as percentage of total cost (%)
Manual labour including transportation	80 - 90
Manual labour for excavation and transported by narrow gauge trucks pushed manually	70 - 80
Manual labour for excavation and transported by narrow gauge trucks power propelled	50 - 60

As in manual earthwork same set of motions are more or less repeated by manual workers, improvement in organization to minimize idle labour assumes special importance, because any small saving in labour expended may lead to substantial savings in cost. Actually, improvement in this respect can be largely brought about by the efforts of foremen.

/So called

So called "activity ratio" will indicate one of these conditions. Its purpose is to indicate for what percentage of a day's work labourers are engaged on their main job, and analyse the rest of the time into various secondary jobs (including idle time) to obtain the data for the improvement of operation and its organisation.

By activity analysis we can get a general idea about efficiency of workers. As an ideal, the job should be so organized and controlled that each worker would perform something good for the planned production continuously throughout the working hours. But it is unavoidable that some percentage of working hours will remain idle without performing any productive activities. Ratio of productive time to total working time is called "activity ratio". In actual practice it is almost impossible to observe the all-day performance of each worker. The usual method is to try to find out by actual observation how many are idle at any particular time by sampling and then deduce results for whole day's working.

As a result of actual observations made on one of the projects in India it was found that activity ratio was 50 per cent.

We must make every effort to increase activity ratio by reducing idle time.

Various methods to improve output have already been discussed under A, B and C above.

E. TIME AND MOTION STUDY

As mentioned before, in manual earthwork the same set of motions is more or less repeated by a large number of workers so that any small saving in labour expended may lead to substantial savings in cost. One way of studying the problem would be to determine the time taken for one cycle of operations and try to eliminate idle time.

Each operation of earthwork consists of the following:

> Excavation (cutting), loading, transporting, unloading, returning. One complete cycle would be from excavation to returning after unloading. After unloading there is the process of grading, compaction and final dressing but these may be left out for purposes of the present study.

/Work done

Work done during the day and time expended on useful work

Activity concerning manual earthwork during the day may be divided as:

Excavation

Loading

Transportation

Unloading

Returning

Maintenance

Rest for lunch

Rest period

Idleness

We can note the time of each process during the day.

As a result of observations, we can find out:

(a) Time of idle work.

We must investigate the causes of idle work and devise ways to minimize this.

(b) Whether the capacity of labourer and equipment are balanced in each process or not? Whether labourers are too many or transporting equipment too large?

(c) Whether the working speed is proper or not?

The standard of working speed can be judged by the measurement of actual working speed for a number of operators.

(d) Is there any special bottleneck in the process? For instance, transporting slope is too steep or inadequacy or lack of transporting path.

(e) To determine the standard process.

According to the results of the working time we can determine the standard process.

A study was made in Japan on earthwork including excavating, loading by manual labour and transport by narrow gauge truck (capacity 0.6 m^3) pushed by manual labour, lead 560 m and average gradient 1/20 downward. The time required for the process of loading, moving, unloading, truck returning and walking (unloaded) was measured and analyzed to find out measures needed for improving the efficiency.

/As a result

As a result of careful analysis it was found that even by allowing

8.00 - 8.10 and 16.50 - 17.00	for preparation	) Working period
12.00 - 13.00	for lunch	) is from 8 a.m.
10.00 - 10.15 and 15.00 - 15.15	for rest	) to 5 p.m.

it should be possible to increase the number of return trips from 19 to 23.

/VII. ROLE OF

VII. ROLE OF MANUAL AND MECHANIZED EARTHWORK AND THEIR COMBINATION

As discussed in chapter III, manual labour has several limitations. In case manual labour has to be employed for earthwork beyond optimum load and lift or for excavating hard soil, under water work, etc. where manual labour alone cannot be effective, it would be best to combine it with machines. Let us first examine the conditions which are suited for earthwork by manual labour and machines before discussing the combination of manual labour and machines.

A. CONDITIONS WHICH ARE SUITED FOR EARTHWORK BY MANUAL LABOUR

(1) Wages for labourers are low.

(2) Speed of construction is not very important.

(3) Small quantities of earthwork are involved and working space is not restricted.

(4) Employment of labour is easy.

(5) Kind of soil is not hard and conditions for excavation and loading are easy.

(6) Lead is less than 100 metres and lift less than 10 metres.

B. CONDITIONS WHICH ARE SUITED TO THE MECHANIZED EARTHWORK

(1) Wages are high.

(2) Working rate is high, as for example, with hard soil, excavation under water or loading to height, etc.

(3) Work is difficult either by manual labour, or even transportation by trucks, etc., as for example, work on uneven topography involving high lifts and in remote places or where space is restricted.

(4) Work where lead and lift is beyond the optimum for manual labour.

(5) Emergency work that has to be done under great pressure and where speed is all important.

/C. COMBINATION OF

C. COMBINATION OF THE EARTHWORK BY MANUAL LABOUR AND MACHINE

Where necessary, it is possible to combine manual labour and machines rationally with a view to increasing the efficiency of earthwork. Combination of earthwork by manual labour and machines would be governed mostly by the conditions prevailing at the working site. We will, therefore, discuss them mainly on the basis of unit cost and efficiency. Certain typical constructions are shown in Table 17.

(1) To determine the capacity of the combination

The most important problem is to balance the capacity of manual labour and machines. There will be a natural tendency for the manual labour to do less work and be idle while working in combination with machines. This will be further increased in case there is lack of balance in the capacity of manual labour and machine. In general, the governing factor will be the capacity of transportation, so that capacity of each process should be fitted to the capacity of transportation. In other words, number of labourers for excavation, loading and unloading should be fitted with the capacity of the transporting machine.

/Table 17

Table 17

DIFFERENT COMBINATIONS

Combinations	Excavation	Loading	Transportation	Embankment
(a) Short distance transportation (lead about 10 to 60 m)				
Combination (1)	M.L.[1/]	M.L.	M.L.	M.L.
" (2)	M.L.	M.L.	Rubber tire wagon	M.L.
" (3)	M.L.	M.L.	Animals	M.L.
" (4)	M.L.	M.L.	Narrow gauge truck	M.L.
" (5)	Bulldozer	Bulldozer	Bulldozer	Bulldozer
(b) Short and medium distance transportation (lead about 50 to 200 m)				
Combination (4)	M.L.	M.L.	Narrow gauge truck	M.L.
" (6)	M.L.	M.L.	Narrow gauge truck driven by animal	M.L.
" (7)	M.L.	M.L.	3-wheel automobile	M.L.
(c) Medium distance transportation (lead about 100 to 600 m)				
Combination (6)	M.L.	M.L.	Narrow gauge truck driven by animals	M.L.
" (8)	M.L.	M.L.	Narrow gauge truck driven by locomotive	M.L.
" (9)	Scraper	Scraper	Scraper	Scraper
(d) Medium and long distance transportation (lead more than 500 m)				
Combination (8)	M.L.	M.L.	Narrow gauge truck driven by locomotive	M.L.
" (10)	Ladder excavator	Ladder excavator	Narrow gauge truck driven by locomotive	M.L.
" (11)	Shovel	Shovel	Dump truck	Bulldozer

1/ M.L. stands for manual labour

/(2) Application of

(2) Application of Bulldozer to earthwork by manual labour

Bulldozer may be used not only for mechanized earthwork but also combined with earthwork by manual labour. It is very useful and increases the efficiency of earthwork by manual labour when used for:

(a) Excavating very thin layers of earth

(b) Excavating hard soil

In these circumstances, bulldozer excavates and pushes the soil to the site near the trucks and wagons to be loaded by manual labour.

(3) Matters that need special attention for each combination

(a) Combination (1)

This is the traditional form of earthwork, and may not be effective for large quantities of earthwork. This method is used in case of small quantities of earth volume where topography, soil condition, etc. are not suitable except for manual labour.

(i) Best suited for lead and lift less than 30 m and 3 m respectively; the limiting lead will be 100 metres.

(ii) It is important to balance the number of labourers transporting the earth with the number of labourers excavating it, so that both sets of labours are continuously busy and no time is lost in waiting by either set.

(iii) The intervening distance between labourers should be fixed carefully to enable them to work with ease.

(iv) Transportation should be continuous from the excavation area to the dumping area, so that no labour passes the same spot more than once on his way from the excavation area to the dumping area and back.

(v) The loading height must be kept less than 1 metre because efficiency will be greatly reduced if the loading height is more than 1 metre.

(vi) The number of implements for transportation, such as cane baskets should always be 25 per cent to 50 per cent more than the number of labourers engaged on transporting earth. When the labourers come back to the excavation area after dumping the earth they should find baskets already filled up and should not have to wait.

/(vii) It is

(vii) It is generally found that labour working in smaller groups gives more per capita production than a large number of labourers working in the same place. Optimum number of labourers working independently would be about 40 to 50 people.

(viii) Path made by the labour for getting on to the top of the excavation pit should be a proper ramp at an easy slope of 1 in 10 and not in the form of steps.

(ix) The maximum distance and lift for which sand and earth can be thrown will be 5 m and 3 m respectively. One shovel-full of earth weighs on the average 7 to 8 kg, 1 cubic metre of earth weighs on the average 1,620 kg and contains 180 to 230 shovel-full. Walking speed of labourer is about 30 to 40 metres per minute.

(b) Combination (2)

The conditions are almost the same as for combination (1).

As the output will be mainly influenced by the gradient of slope and rolling resistance between rubber tires and earth, it is necessary to make the gradient of slope of transporting path as easy as possible.

(c) Combination (3)

This method has been very popular in some of the countries of the region with an abundance of cheap animal labour. Before the introduction of machines, earthwork on some of the large barrages on sand foundation was completed with the help of donkeys. Donkeys in India carry about 2 cu ft of earth, but it should be possible to increase the capacity by 10 to 20 per cent.

(d) Combination (4)

This will be the lowest resistance method by manual labour.

(i) It is necessary to avoid small radius of curvature and steep slopes, especially to avoid more than 1/50 of up-grade if possible. The brake will be necessary, if the length of slope of 1/30 is over 80 m.

(ii) The arrangement of the track will greatly affect efficiency, and it is necessary to avoid confusion with consequent accidents and breakdowns.

(iii) The track has no doubt to be moved from place to place to suit the conditions of the work, but as shifting of the track is often troublesome it should be kept to the minimum.

(iv) Generally, the track will be single, but if possible it should be double with separate tracks for forward and return trips, Alternatively, loops at suitable points will help to increase the efficiency.

/(e) Combination (5)

(e) Combination (5)

This method is efficient for short distance transportation say 50 to 60 m, and is very economical for 10 to 30 m lead.

(f) Combination (6)

The condition is almost the same as combination (4). It means 3 or 4 narrow gauge trucks driven by animals, and is economical and efficient for medium distance transportation in a place where there is an abundance of animals with cheap fodder.

(g) Combination (7)

The 3-wheel automobile (dump type) is a small size transportation vehicle (capacity is about 1 to 1.2 m^3) very easy for unloading of earth and turning direction. This should be useful for about 100 to 200 m of transportation, but not suitable for soft soil road conditions.

(h) Combination (8)

This is almost same as combination (4) and generally 1 cubic metre dump truck is used when transported by locomotive in order to keep unloading time to minimum. The usual combination in Japan is as follows:

Table 18[1/]

COMBINATIONS OF TRUCKS AND LOCOMOTIVES OF VARYING CAPACITY

Capacity of truck m^3		Rail Kg/m	Gauge mm	Locomotive ton
Steel	0.6	6 - 9	610	4 - 7
Wooden	0.6	6 - 9	610	4 - 7
Steel	1.0	9	610	4 - 7
Wooden	1.0	9	610	4 - 7
Steel	3.0	20	1067	20
Wooden	3.0	20	1067	20

1/ "Mechanized Earthwork Construction" by Y. Saito p. 169

(i) Combination (9)

This method is very effective for transportation for a distance of 100 to 600 metres. Using the pusher would add to efficiency.

(j) Combination (10)

For this ladder excavator (Loader) is used, This method will be suitable for large-scale excavation of channels and earthwork of embankment etc. in sandy soil, but not suitable for hard soil.

The capacity of the machine is 120 cubic metre or 60 cubic metre per hour. The machine is effective though travelling is not so easy.

(k) Combination (11)

This method is useful under most conditions and the number of dump trucks should be fixed to suit the haulage distance and the capacity of the power shovel.

(4) Examples of combination of earthwork

(a) Results of analysis of data

(i) Output per hour per man

Output per hour per man can be calculated from the data for working rate and output, shown in chapter V, A and B; some assumptions will, however, be necessary. The results of output per hour per man are shown in graph 4. (See Appendix for details of calculations).

(ii) Unit cost

The results are illustrated in Graphs 1, 2 and 3.

(b) Consideration of rational combination of the earthwork

From the study of graphs 1, 2 and 3, the following combinations of earthwork for given loads are suggested:

(i) Excavation and loading (Graph 1)

The most economical means would be manual labour for loading to height less than 1 metre and power shovel for loading height more than 1 metre for common soil. Power shovel will be cheaper in case of hard soil with loading height of more than 1 metre involving large quantities of earthwork.

/(ii) Lead 10 to

(ii) Lead 10 to 60 m (Graph 2)

The most economical method would be bulldozer; next comes rubber tire wagon. Manual labour is most expensive in this case. Bulldozer should therefore be used, if possible, and where difficult rubber tire wagon may be used. Manual labour should be used only for small quantities of earthwork or for the work which cannot be executed except by manual labour.

(iii) Lead 50 to 200 m (Graph 2)

The most economic method will be to use scraper (crawler tractor-driven) but if scraper is not suitable, narrow gauge truck animal driven or manual labour and 3-wheel automobile should be used.

(iv) Lead 100 to 500 m (Graph 3)

Scraper (crawler tractor-driven) and motor scraper are most economical for leads less than 300 m and 700 m respectively. Where lead is more than 400 and 800 m respectively, power shovel with dump trucks and narrow gauge truck locomotive driven will be more economical.

(v) Lead more than 500 m (Graph 3)

Motor scraper and power shovel with dump truck will be economical, provided the number of dump trucks matches the capacity of the power shovel. Sometimes due to lack of dump trucks, power shovel cannot operate to full capacity. In that case, the unit cost will be nearly the same both for the power shovel and dump truck and narrow gauge truck locomotive driven.

The results discussed above are given only as illustrations. When the efficiency of machines increases further, unit cost would be lower. If, however, the purchase price of machines increases, the unit cost would be higher, so that unit cost will vary according to the conditions prevailing at the time.

In practice it would be necessary to calculate the unit cost according to the actual conditions prevalent in the country and determine the most suitable and economical combination.

/VIII. SUMMARY AND

VIII. SUMMARY AND CONCLUSIONS

The countries of the region have in hand a heavy programme of water resources development involving large quantities of earthwork. With the increase in the size of projects, there has recently been a growing tendency to use machinery for earthwork. As these countries with a rapidly increasing population and a slow rate of industrialization have abundant manpower, efforts should be directed towards improving the efficiency of manual labour.

Given the amount of earthwork being done or contemplated under the development plans of the country, it is felt that a stage has been reached when the entire question should be carefully examined with a view to:

(a) Making more effective use of manual labour through improvements in implements, labour incentives, welfare facilities, etc.

(b) Determining how far manual labour, alone or in combination with machines, should be adopted.

It will be appreciated that a saving of even a small percentage in the earthwork cost of water resources development projects will ultimately lead to substantial saving and thus more than justify this study.

There are a number of factors affecting output of earthwork by manual labour:

Natural conditions such as climate

Topography and nature of the soil

Physical conditions of labourers

Implements used

Wage incentives, bonus system, labour welfare and recreation and medical facilities

Working conditions like lead and lift and executive organization.

Nature of earthwork - if the soil to be excavated is very hard or if it is slush involving under-water work, manual labour may be difficult, if not impossible. Manpower required for the excavation of various types of soil has been set out in detail. Dry hard clay, for example, requires about four times the manpower needed for soft soil.

/The increase

The increase in manpower with various loading heights for common soil has also been given, from which it is clear that, with loading height above one metre, the manpower required per cubic metre of earthwork increases rapidly. In the case of a loading height of 2.1 metres the manpower required is double that at zero loading height.

The increase in manpower required for the excavation of a cubic metre of earth under different depths of water has also been given and it has been shown that, for the excavation under 0.6 m depth of water, the manpower required is about four times that at zero depth.

The increase in manpower required with an increase in leads and lifts has also been shown. The optimum lead and lift for manual earthwork may be taken as 30 m to 50 m of lead and 3 m to 4.5 m of lift, and the critical limit of lead may be taken as 100 m.

Where large quantities of earthwork have to be completed with a maximum of speed, machines score heavily over manual labour. A two-yard excavator with about 10 men can do a piece of work in one day which the same number of men will take one month to complete by manual labour.

Machines can sometimes cut down the construction schedule by one-half, so that the project will start to give benefits much earlier, with consequent returns on the capital invested.

Similarly, machines are indispensable for compaction. Where large quantities of earthwork have to be compacted, as in the construction of a dam or high dykes, there is no alternative except to use machines.

One way of quickening the pace of earthwork by manual labour is to increase the labour force, but for a large multi-purpose project there are obvious limitations to the size of the work force. Labour has to be procured for different sections of the project in progress at the same time, and a large labour force creates its own problems of housing, sanitation etc. In addition, manual labour has generally to be attracted by heavy advances which add to overhead expenses. Overhead expenses comprising hutting charges, depreciation and repairs to tools, transport and watchman charges, advances and food arrangements, have been estimated at 15 per cent. To this we have to add lighting, sanitation, water supply, medical services and recreation facilities.

/If manual

If manual labour has its limitations, mechanization creates its own problems in under-developed countries where there is plenty of manpower and general under-employment. On an average, it may be taken that about 17 men operating a machine ($2\frac{1}{2}$ cubic yard capacity shovel) can give the same outturn as 300 men doing manual earthwork in the same period. Mechanization reduces the number of employees drastically, and this should serve as a warning against over-mechanization. Generally in any given project there are sectors like canals involving earthwork with moderate leads and lifts, so that by judicious use of machinery a good balance can be maintained between work done manually and by machines.

It has also to be remembered that considerable expenditure of foreign exchange is involved in the initial purchase and procurement of spare parts. The average requirements of spare parts are of the order of 15 to 20 per cent of the cost of equipment per annum, so that during the economic life of a machine spare parts generally cost as much as the capital cost of the machine. This involves recurring expenditure of foreign exchange. Fuel and lubricating oil also have to be imported in the case of most countries, adding to the recurring foreign exchange costs of operation.

In order to maintain these expensive machines, well-equipped workshops have to be set up, and sometimes it is difficult to man them efficiently in view of the shortage of trained mechanics.

There is also the question of the training of operators and mechanics. In this region, there is a shortage of trained technical personnel. For proper use, heavy earthmoving machines need skilled operators. This alone is a big bottleneck for large-scale mechanization although training schemes have been undertaken in some of the countries. Plant planning for earthmoving equipment needs expert knowledge and has to be done with great care. Similarly, haul roads have to be carefully planned and well maintained. Efficient management and sound planning involve the maintenance of accurate records of the actual working of each machine, which needs a good deal of organization.

/Assuming net

Assuming net working hours are seven, the average manpower required has been calculated per cubic metre for the following conditions:

(i) Excavation and loading by manual labour for different kinds of soil and for different loading heights.

(ii) Excavation by manual labour, including transportation for different kinds of soil and for different leads and lifts.

(iii) Excavation by manual labour and transportation by rubber tyre wagon for common soil and hard clay and for different leads.

(iv) Excavation of common soil and hard clay by manual labour and transportation by narrow gauge truck for different leads.

(v) Excavation by manual labour and transportation by narrow gauge truck animal-driven for different leads.

(vi) Excavation by manual labour and transporation by narrow gauge truck locomotive driven for different leads both for common soil and gravel earth.

Average output per hour of the following machines has also been given:

(i) Bulldozer capacity 15 tons for leads 10 to 60 metres.

(ii) Scraper capacity 8 cubic yards for leads 100 m to 600 m.

(iii) Power shovel capacity 3/4 cubic yard both for easy work and hard work.

From the above graphs 1, 2, 3 and 4 have been drawn. (For detailed calculations of a few typical cases see appendix).

Graph 1 - Shows unit cost per cubic metre for excavation and loading for different loading heights by manual labour (common soil and hard clay) and power shovel (easy work and hard work).

Graph 2 - Shows unit cost per cubic metre for leads zero to 200 m for:

(i) Manual labour
(ii) Using rubber tyre wagon
(iii) Narrow gauge truck manually operated
(iv) Narrow gauge truck animal driven
(v) 3-wheel automobile
(vi) Bulldozer
(vii) Scraper

/Graph 3

Graph 3 - Shows unit cost per cubic metre for leads 100 to 2,000 m for:

(i) Narrow gauge truck manually operated
(ii) Narrow gauge truck animal driven
(iii) Narrow gauge truck locomotive driven
(iv) Scraper 8 cubic yards
(v) Motor scraper 11 cubic yards
(vi) Power shovel and dump truck.

Graph 4 - Shows output per hour per man in cubic metre for leads zero to 200 m, in case of:

(i) Manual labour (for leads 30 to 90 m only)
(ii) Using rubber tyre wagon (for leads 10 to 90 m)
(iii) Bulldozer (leads 10 to 60 m)
(iv) 3-wheel automobile (leads 50 to 200 m)
(v) Scraper 8 cubic yard (leads 100 to 200 m)
(vi) Narrow gauge truck animal driven (leads 100 to 200 m)
(vii) Narrow gauge truck manually operated (leads 100 to 200 m).

These graphs show the unit rates of different types of earthwork to serve as a guide to select the most economical unit to suit the particular conditions.

Some suggestions have been offered to increase the efficiency and reduce the unit cost of manual earthwork. These are:

(i) to use right type of implements both for excavation and loading
(ii) to select borrow pits as close to the site of work as possible
(iii) to make the upward gradient as small as possible, and where possible work on the downward gradient when loaded. In case of level, the output will be 40 - 50 per cent bigger than in the case of 1/20 upward gradient with rubber tyre wagons
(iv) In order to load as quickly as possible, to keep excavation depth and loading height down to a minimum
(v) to make use of animals for transportation, where possible

/(vi) to select

(vi) to select the mode of transportation with minimum resistance

(vii) to reduce the time of the complete cycle of excavation, loading, transportation etc. as far as possible.

(viii) to organize the work properly, so that idle time is reduced to the minimum.

The "activity ratio", which is the ratio of productive time to total working time, should be as high as possible.

Allowing for time for lunch and rest, it should be possible to improve upon the time spent on the complete cycle of earthwork for which it would be necessary to:

(a) investigate the causes of idle work and devise ways to eliminate them

(b) ensure that the capacity of labourers and equipment are balanced (Capacity of transporting equipment should match the labour engaged on excavation)

(c) ensure good working speed

(d) remove all bottlenecks, like slopes which are too steep, or inadequate paths for transportation.

Labour welfare facilities combined with wage incentive and bonus systems play an important part in the daily output of labour. Improvements in housing conditions, drinking water, sanitation arrangements, medical and recreation facilities go a long way to creating conditions conducive to increased output.

After a discussion of limitations of manual labour and unit cost for various modes of earthwork, different combinations of manual labour and machines are examined with a view to finding out the most economical and efficient arrangements under different conditions. Conditions which are suited to earthwork by manual labour and machines have been given in detail. Different types of combinations are described giving particular conditions under which each type of combination would be suitable.

/From graphs 1,

From graphs 1, 2 and 3 it is clear that:

(i) For excavation and loading common soil, the use of manual labour for loading to height of less than one metre and that of power shovels for loading height in excess of one metre would be most economical

(ii) For a lead of 10 to 60 metres (Graph 2), the most economical means is bulldozer; thereafter a rubber tyre wagon

(iii) For a lead of 50 to 200 metres (Graph 2), a scraper will be most economical

(iv) For a lead of 100 to 600 metres (Graph 3), a scraper (crawler tractor-driven) and motor scraper are most economical for leads of less than 300 metres and 700 metres respectively. For leads of more than 400 and 800 metres respectively, power-shovels with dump trucks and narrow gauge trucks, locomotive-driven, will be more economical, provided the number of dump trucks matches the capacity of the power-shovel.

These are only a few general illustrations. In actual practice, however, it would be necessary to calculate the unit cost under the conditions prevailing in the particular country and then decide on the most suitable and economical combination. It is also evident that continuity of construction by earthmoving machinery is essential to achieve economical rates, since the unit rates of earthwork based on the total expenditure decline progressively as the earthmoving equipment is utilized for longer period of its life.

/Appendix

Appendix

CALCULATIONS OF UNIT COST AND OUTPUT PER HOUR

A. EXCAVATION AND LOADING BY MANUAL LABOUR

Calculating only for common soil

(1) Working rate (Manpower required per day per m^3)

Working hours are 7 hours per day and from Table 6 working rate is as follows:

Loading height m / Kind of soil	0	0.3	0.6	0.9	1.2	1.5	1.8	2.1
Common soil	0.10	0.102	0.104	0.108	0.114	0.126	0.148	0.204

(2) Output per hour per man

As working rate is 0.10 for loading height zero, so a man works (output) 10 cubic metres per day (7 hours). Therefore, output per hour per man is $(\frac{10}{7} = 1.43$. Calculating similarly for other loading heights output per hour per man is:

Kind of soil	Output per hour per man in m^3 for loading height							
	0	0.3	0.6	0.9	1.2	1.5	1.8	2.1
Common soil	1.43	1.40	1.37	1.32	1.25	1.13	0.97	0.70

(3) Unit cost

Assuming labour wage per day is 400 in yen and administration expenses area 20 per cent of the unit cost. Working rate is 0.10 for loading height zero, which will cost 40 yen per cubic metre (400 x 0.1 = 40), and administration expenses are 20 per cent of unit cost. Therefore unit cost for loading height zero is $40 \times \frac{1}{0.8} = 50$ yen.

Similarly we can calculate unit cost for different loading heights. The results are as follows:

/Kind of soil

Kind of soil	Unit cost per m^3 for loading height								
	0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	m
Common soil	50	51	52	54	57	63	74	101	yen

As the depreciation of implements will be small, it will be looked after by the administration expenses.

The above is illustrated in Graph 1. .

B. EXCAVATION AND LOADING BY POWER-SHOVEL

Capacity of Power-Shovel is 3/4 cubic yard and assuming working hours per day are 6 hours.

(1) Output per hour per man

The average output per hour over a long period is given below:1/

Kind of work	Output per hour m^3/hr
For easy work	60
For hard work	40

Assuming 4 men worked on a shovel including mechanics, output per hour per man will be as follows:

Kind of work	Output per hour per man m^3/hr/man
For easy work	15
For hard work	10

(2) Unit cost

Total expenses per hour will consist of operation, repairs, depreciation, transportation and administrative expenses.

/(a) Operation

1/ See Table 14.

(a) Operation expenses per hour

From actual observation, we get the following results:

Items	Amount per hour	Unit price	Amount
Gasoline	0.01 litre	40	4
Diesel oil	9 "	20	180
Mobile oil	0.3 "	150	45
Gear oil	0.15 "	150	23
Grease	0.15 kg	130	20
Waste cotton	0.04 kg	50	2
Operator	0.2 man	800	160
Assistant	0.2 man	500	100
		Total	534 in yen

(b) Expenses on repairs per hour

Assuming economical life of power-shovel as 10,000 working hours, total expense on repairs during economical life will be 1.5 times the purchase price. Purchase price is 8.2 million yen. So that average expenses on repairs per hour will be as follows:

$$\text{Expenses on repairs per hour} = \frac{8,200,000 \times 1.5}{10,000} = 1,230 \text{ yen.}$$

(c) Depreciation expenses per hour

Assuming residual value is 10 per cent of purchase price, depreciation expenses per hour will be as follows:

$$\text{Depreciation expenses per hour} = \frac{8,200,000 \times (1-0.1)}{10,000} = 738 \text{ yen.}$$

(d) Transportation and administration expenses per hour

Broadly speaking transportation expenses and administration expenses are 8 per cent and 20 per cent respectively of total expenses.

(e) Total expenses per hour

As the expenses for operation, repairs, and depreciation come to 72 per cent, total expenses per hour will be as follows:

$$\text{Total expenses per hour} = \frac{1}{0.72}(534 + 1,230 + 738) = 3,475 \text{ yen}$$

/(f) Unit cost

(f) Unit cost

From the total expenses per hour and output per hour, the unit cost will be as follows:

Kind of work	Total expenses per hour	Output per hour m^3/hr	Unit cost per m^3 Yen/m^3
Easy work	3,475	60	58
Hard work	3,475	40	87

The above results are also illustrated in Graph 1.

C. EARTHWORK BY MANUAL LABOUR INCLUDING TRANSPORTATION

Let us calculate for common soil, assuming loading height 0.6 m and lift 3 m.

(1) Working rate (Manpower required per m^3)

Working hours are 7 hours per day. From Tables 6 and 7 working rate is as follows:

Manpower required per m^3 per day							
Kind of soil	For excavation	For transportation Lead m			For excavation and transportation		
		30	60	90	30	60	90
Common soil	0.104	0.154	0.209	0.264	0.258	0.313	0.368

(2) Output per hour per man

As working rate is 0.258 for lead 30 m, so a man can accomplish (output per man per day) $\frac{1}{0.258}$ = 3.87 cubic metre per day (7 hours). Therefore output per hour per man is $\frac{3.87}{7}$ = 0.55 cubic metre. In the same way output per hour per man for different leads is as follows:

Kind of soil	Lead m		
	30	60	90
Common soil	0.55	0.46	0.39

These results have been shown in Graph 4.

/(3) Unit cost

(3) Unit cost

Assuming labour wage is 400 in yen and administration expenses are 20 per cent of unit cost. As working rate is 0.258 for lead 30 m, so expense for labourer is 400 x 0.258 = 103.2 in yen per cubic metre, and administration expenses are 20 per cent of unit cost. Therefore unit cost for lead 30 m is $\frac{1}{0.8}$ x 103.2 = 130 in yen. Similarly, we can calculate unit cost for different leads. The result is as follows:

Kind of soil	Lead m		
	30	60	90
Common soil	130	156	184

As the expenses of implements will be small, these may be assumed to be covered by administration expenses.

The above results have been illustrated in Graph 2.

D. EARTHWORK BY BULLDOZER

Capacity of Bulldozer is 15 tons (D-7 class) and assuming working hours per day as 6 hours.

(1) Output per hour per man

Taking average output per hour over a long period with 4 men working for a Bulldozer including mechanic, output per hour per man will be as follows:

Lead	Output per hour 1/ m^3/hr	Output per hour per man m^3/hr/man
10	144	36
20	75	18.8
30	55	13.8
40	43	10.8
50	33	8.3
60	27.5	6.9

These results are shown in Graph 4.

/(2) Unit cost

1/ From Table 12.

(2) Unit cost

Total expenses per hour will consist of operation, repairs, depreciation, transportation and administration expenses.

(a) Operation expenses per hour

Operation expenses per hour will be as follows:

Items	Amount per hour	Unit price	Amount
Gasoline	0.2 litre	40	8
Diesel oil	12 "	20	240
Mobile oil	0.4 "	150	60
Gear oil	0.3 "	150	45
Grease	0.2 kg	130	26
Waste cotton	0.04 kg	50	2
Operator	0.2 man	800	160
Assistant	0.2 man	500	100
		Total	641 in yen

(b) Expenses on repairs per hour

Assuming economical life of bulldozer is 10,000 working hours, total expenses on repairs during economical life will be 1.9 times the purchase price. Purchase price is 7.5 million yen:

So, average expenses on repairs per hour will be as follows:

$$\text{Expenses on repairs per hour} = \frac{7,500,000 \times 1.9}{10,000} = 1,420 \text{ yen.}$$

(c) Depreciation expenses per hour

Assuming residual value is 10 per cent of the purchase price, depreciation expenses per hour will be:

$$\text{Depreciation expenses per hour} = \frac{7,500,000 \times (1-0.1)}{10,000} = 675 \text{ yen.}$$

/(d) Transportation

(d) Transportation and administrative expenses per hour

Transportation expenses and administrative expenses are roughly 6 per cent and 20 per cent respectively of total expenses.

(e) Total expenses per hour

As the expenses for operation, repairs and depreciation represent 72 per cent of the total, total expenses per hour will be:

$$\text{Total expenses per hour} = \frac{1}{0.72}(641+1420+675) = 3{,}800 \text{ yen.}$$

(f) Unit cost

From the total expenses per hour and output per hour, the unit cost will be as follows:

Lead m	Output per hour m^3/hr	Unit cost Yen/m^3
10	144	26.4 1/
20	75	51
30	55	69
40	43	88
50	33	155
60	27.5	138

These results have been illustrated in Graph 2.

E. EARTHWORK BY SCRAPER

Capacity of a scraper is 8 cubic yards, (15 ton tractor driven) and assuming working hours per day as 6 hours.

(1) Output per hour per man

Average output per hour over a long period with 4 men working for a scraper including mechanics, output per hour per man will be as follows:

/Table

1/ $26.4 = \frac{3{,}800}{144}$

Lead m	Output per hour 1/ m3/hr	Output per hour per man m3/hr/man
100	64	16
200	43	10.8
300	31	7.8
400	23	5.75
500	19.2	4.80
600	17	4.25

See graph 4.

(2) Unit cost

Total expenses per hour will consist of operation, depreciation, repairs, transportation and administration expenses.

(a) Operation expenses per hour

Operation expenses per hour will be as follows:

Items	Amount per hour	Unit price	Amount
Gasoline	0.2 litre	40	80
Diesel oil	14 "	20	280
Mobile oil	0.5 "	150	75
Gear oil	0.4 "	150	60
Grease	0.3 kg	130	39
Waste cotton	0.06 kg	50	3
Operator	0.2 man	800	160
Assistant	0.2 man	500	100
		Total	797 in yen

/(b) Expenses on

1/ From table 13.

(b) Expenses on repairs per hour

Assuming economical life of a scraper is 10,000 working hours, total expenses on repairs during economical life are 1.2 times the purchase price. Purchase price is 3,000,000 in yen for a scraper

Average expense for repairs per hour will be:

Repairs per hour for scraper = $\frac{3,000,000 \times 1.2}{10,000}$ = 360 in yen

Repairs per hour for tractor = 1420[1/] in yen

Total expenses on repairs per hour = 360+1420 = 1780 in yen

(c) Depreciation expenses per hour

Assuming residual value is 10 per cent of the purchase price. Purchase price of tractor and scraper is 7,500,000+3,000,000 = 10,500,000 in yen, and depreciation expenses per hour will be:

Depreciation expenses per hour = $\frac{10,500,000 \times (1 - 0.1)}{10,000}$ = 945 in yen

(d) Transportation and administration expenses per hour

Transportation and administration expenses may be taken as 8 per cent and 20 per cent respectively of total expenses.

(e) Total expenses per hour

As the expenses on operation, repairs and depreciation correspond to 72 per cent of total expenses, total expenses per hour will be:

Total expenses per hour = $\frac{1}{0.72}$ (797+1780+945) = 4892 in yen.

(f) Unit cost

From the total expenses per hour of 4892 yen and output per hour given above, the unit cost per m^3 is as follows:

/Lead

1/ Vide section D 2(b) of Appendix

Lead	Output per hour m^3/hr	Unit cost yen/m^3
100	64	77
200	43	114
300	31	158
400	22	223
500	19.2	255
600	17	288

These results have been illustrated on Graphs 2 and 3

F. EARTHWORK BY MANUAL LABOUR AND TRANSPORTED BY NARROW GAUGE TRUCK LOCOMOTIVE DRIVEN

Considering only for common soil.

(1) Working rate (Manpower and materials required per 100 m^3)

With working hours of 7 hours per day, from table 11 working rate is as follows:

Lead m	Output per day (7 hours) m^3	Working rate per 100 m^3						
		Labourer	Operator	Assis-tant	Gaso-line litre	Mobile oil litre	Grease kg	Gear oil litre
500	210	21	0.5	0.5	26	0.6	0.11	2
700	139	22	0.5	0.5	29	0.7	0.13	2.3
1000	157	23	0.6	0.6	32	0.8	0.14	2.6
1500	136	24	0.7	0.7	37	0.9	0.15	2.8
2000	126	26	0.8	0.8	48	1.1	0.17	3.0

(2) Output per hour per man

As working rate is 21 labourers, 0.5 operator and 0.5 assistant for a lead of 500 m, 22 workers will produce 100 cubic metres per day (7 hours). Therefore, output per hour per man is $\frac{100}{22} \times \frac{1}{7} = 0.65\ m^3$, similarly, for other leads:

/Table

Lead m	Number of workers for 100 m^3, 7 hours working	Output per hour per man m^3/hr/man
500	22	0.65
700	23	0.62
1000	24.2	0.59
1500	25.4	0.56
2000	27.6	0.52

(3) Unit cost

(a) Excavation and transportation expenses

With known wages and unit price of materials, excavation and transportation expenses, can be worked out from the working rate as follows:

Wage and unit price

Manual labour	400	in yen	
Operator	800	"	
Assistant	500	"	
Gasoline	40	"	per litre
Mobile oil	150	"	per litre
Grease	130	"	per kg
Gear oil	50	"	per litre

Excavation and transportation expenses

Lead m	Excavation and transportation expenses for 100 m^3 in yen								yen/m^3
	Labour	Operator	Assistant	Gasoline	Mobile oil	Grease	Gear oil	Total	
500	8400	400	250	104	90	14	100	9358	94
700	8800	400	250	116	105	17	115	9803	98
1000	9200	480	300	128	120	18	130	10376	104
1500	9600	560	350	148	135	20	140	10953	110
2000	10400	640	400	192	165	22	150	11969	120

/(b) Expenses on

(b) Expenses on repairs

(i) Locomotive

Assuming economical life of locomotive (7 tons) is 9,000 working hours, and total expenses on repairs during economical life is 1.8 times the purchase price and purchase is 2.5 million yen.

Average expenses on repairs per hour will be as follows:

$$\text{Expenses on repairs per hour} = \frac{2,500,000 \times 1.8}{9,000} = 500 \text{ yen}$$

We can get output per hour from the table of working rate. For instance, in case of lead 500 m output per day is 210 m^3, so output per hour is $\frac{210}{7} = 30\ m^3$. Expenses on repairs per m^3 therefore are 500/30 = 16.7 in yen, similarly calculating for different leads:

Lead m	Output per hour m^3/hr	Expenses on repairs Yen/m^3
500	30	16.7
700	27	18.5
1000	22.5	22.2
1500	19.4	22.8
2000	18	27.8

(ii) Truck, rail and sleeper

Maintenance expenses of truck may be taken as 3,000 in yen per year per truck and for rail with sleeper as 3 per cent of purchase price per year, with number of trucks as 20, and worked for 220 days in a year.

Total expenses for repairs of trucks will be 3000 x 20 = 60,000 in yen per year. Rail is 12 kg per metre and purchase price is 85,000 in yen per ton. Weight of rail and steel sleeper, etc. will be calculated as follows:

For a lead of 500 m rail length is 500 x 4 = 2,000 m (double track). Weight of rail is 24 tons and sleeper etc. should weigh 10 per cent of weight of rails. Weight of rail and sleeper together will be 26.4 tons and its cost will be 2.244 million yen. So expenses on repairs will be 2,244,000 x 0.03 = 67,320 in yen. This may be taken as 70,000 in yen, calculating similarly for other leads.

/Table

Lead m	Expenses on maintenance per year		
	Truck	Rail and Sleepers	Total in yen
500	60,000	70,000	130,000
700	60,000	90,000	150,000
1,000	60,000	140,000	200,000
1,500	60,000	200,000	260,000
2,000	60,000	270,000	330,000

Output per year is calculated from output per day and number of working days (220 days), so maintenance expenses per m^3 will be as follows:

Lead m	Output per day m^3	Output per year m^3	Total repairs expenses in yen	Repair expenses yen/m3
500	210	46,200	130,000	2.8
700	189	41,580	150,000	3.6
1,000	157	34,540	200,000	5.8
1,500	136	29,920	260,000	8.7
2,000	126	27,720	330,000	11.9

Expenses on repairs per m^3 for locomotive, trucks and rail together will be as follows:

Lead m	Expenses on repairs		
	Locomotive yen/m3	Truck, rail and sleeper yen/m3	Total yen/m^3
500	16.7	2.8	19.5
700	18.5	3.6	22.1
1,000	22.2	5.8	28.0
1,500	25.8	8.7	34.5
2,000	27.8	11.9	29.7

/(c) Depreciation

(c) Depreciation expenses

(i) Locomotive

Assuming residual value as 10 per cent of purchase price, purchase price as 2.5 million in yen and economical life as 9,000 hours, depreciation expenses per hour will be:

$$\text{Depreciation expenses per hour} = \frac{2,500,000 \times (1-0.1)}{9,000} = 250 \text{ in yen.}$$

Depreciation expenses per m^3 for different leads will be:

Lead m	Output per hour m^3/hr	Depreciation per m^3 yen/m^3
500	30	8.3 1/
700	27	9.3
1,000	22.5	11.1
1,500	19.4	12.9
2,000	18	13.9

(ii) Truck and rail

With purchase price of a truck as 130,000 in yen and number of trucks as 20, and double track, purchase price of trucks will be 130,000 x 20 = 2.6 million in yen and purchase price of rail etc. will be as already calculated under repair charges.

Assuming this purchase price depreciates over 250,000 cubic metres (life 8 to 10 years) depreciation expenses per cubic metre will be:

Lead m	Purchase price in yen: Trucks	Rail & Sleepers	Total	Depreciation expenses yen/m3
500	2,600,000	2,244,000	4,844,000	19.4 2/
700	2,600,000	3,149,000	5,749,000	23
1,000	2,600,000	4,490,000	7,090,000	28.4
1,500	2,600,000	6,730,000	9,330,000	37.3
2,000	2,600,000	8,980,000	11,580,000	46.2

/Therefore,

1/ $\frac{250}{30} = 8.3$

2/ $\frac{4,844,000}{250,000} = 19.4$

Therefore, depreciation expenses per m^3 for locomotive, trucks and rails will be as follows:

Lead m	Depreciation expense per m^3		yen/m^3
	Locomotive	Truck and Rail	Total
500	8.3	19.4	27.7
700	9.3	23	32.3
1,000	11.1	28.4	39.5
1,500	12.9	37.3	50.2
2,000	13.9	46.2	60.1

(d) Transportation and administration expenses

Assuming transportation expenses and administration expenses are 3 per cent and 20 per cent respectively of unit cost.

(e) Unit cost

As the expenses on account of excavation, repairs and depreciation correspond to 77 per cent of unit cost, the unit cost will be:

Lead m	Expenses per m^3 yen/m^3				Unit cost yen/m^3
	(a)	(b)	(c)	(a)+(b)+(c)	
500	94	19.5	27.7	141.2	183 1/
700	98	22.1	32.3	153.4	199
1,000	104	28.0	39.5	171.5	222
1,500	110	34.5	50.2	194.7	253
2,000	120	39.7	60.1	219.8	286

These are illustrated on Graph 3.

(a) = Excavation and transporting expense per m^3

(b) = Repair charges per m^3

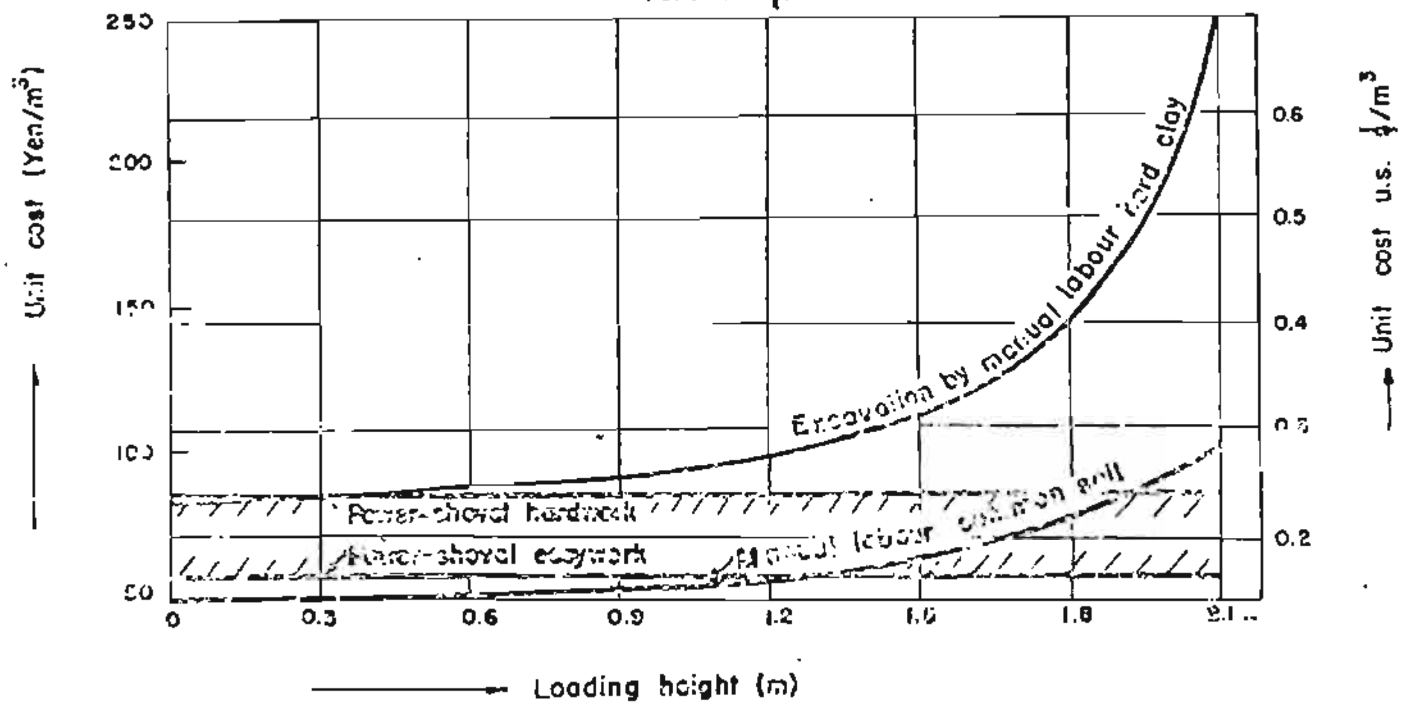
(c) = Depreciation expenses per m^3

1/ $\frac{141.2}{0.77} = 183$

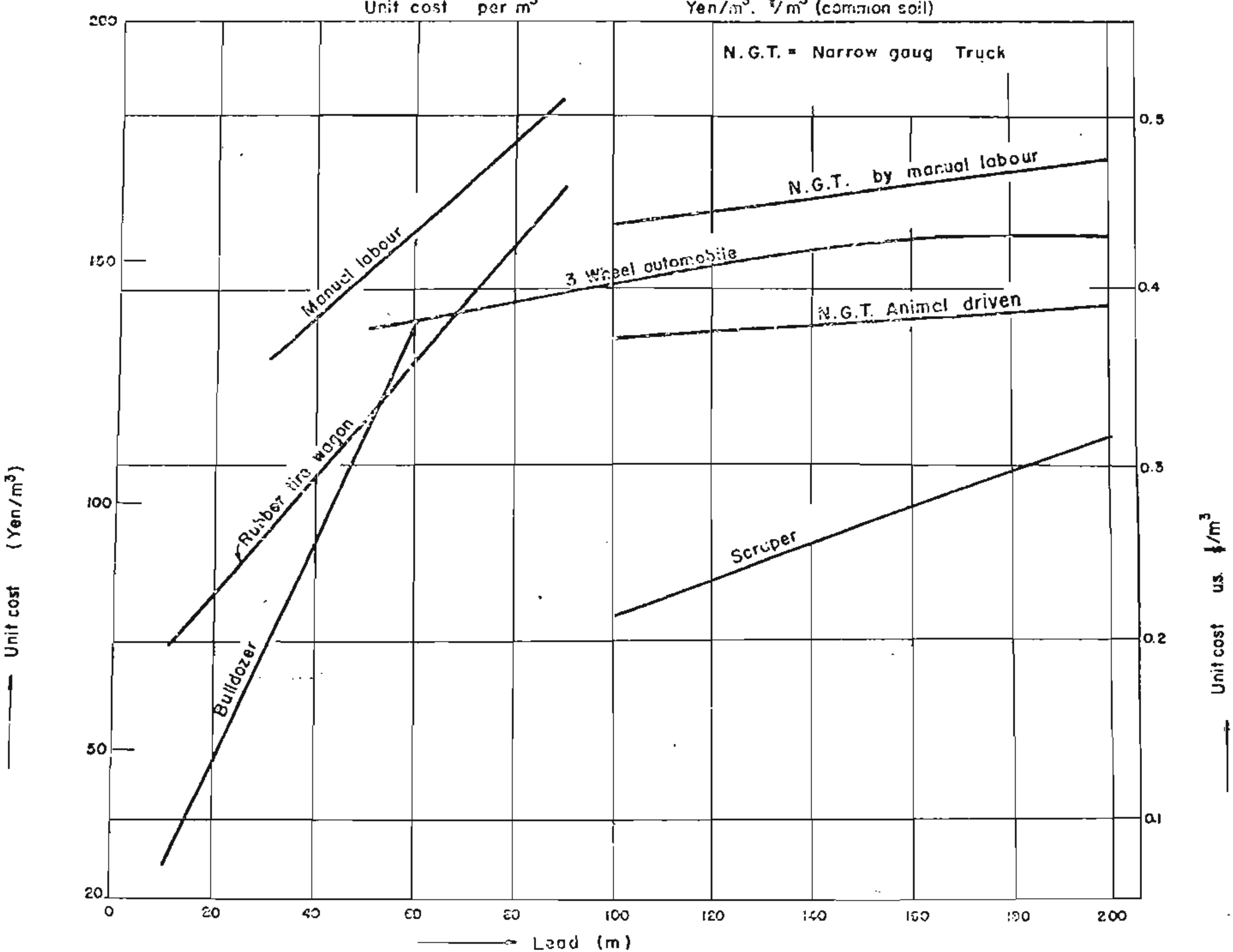
GRAPH - I

Unit cost excavation and loading

Yen/m³ $/m³



GRAPH – 2

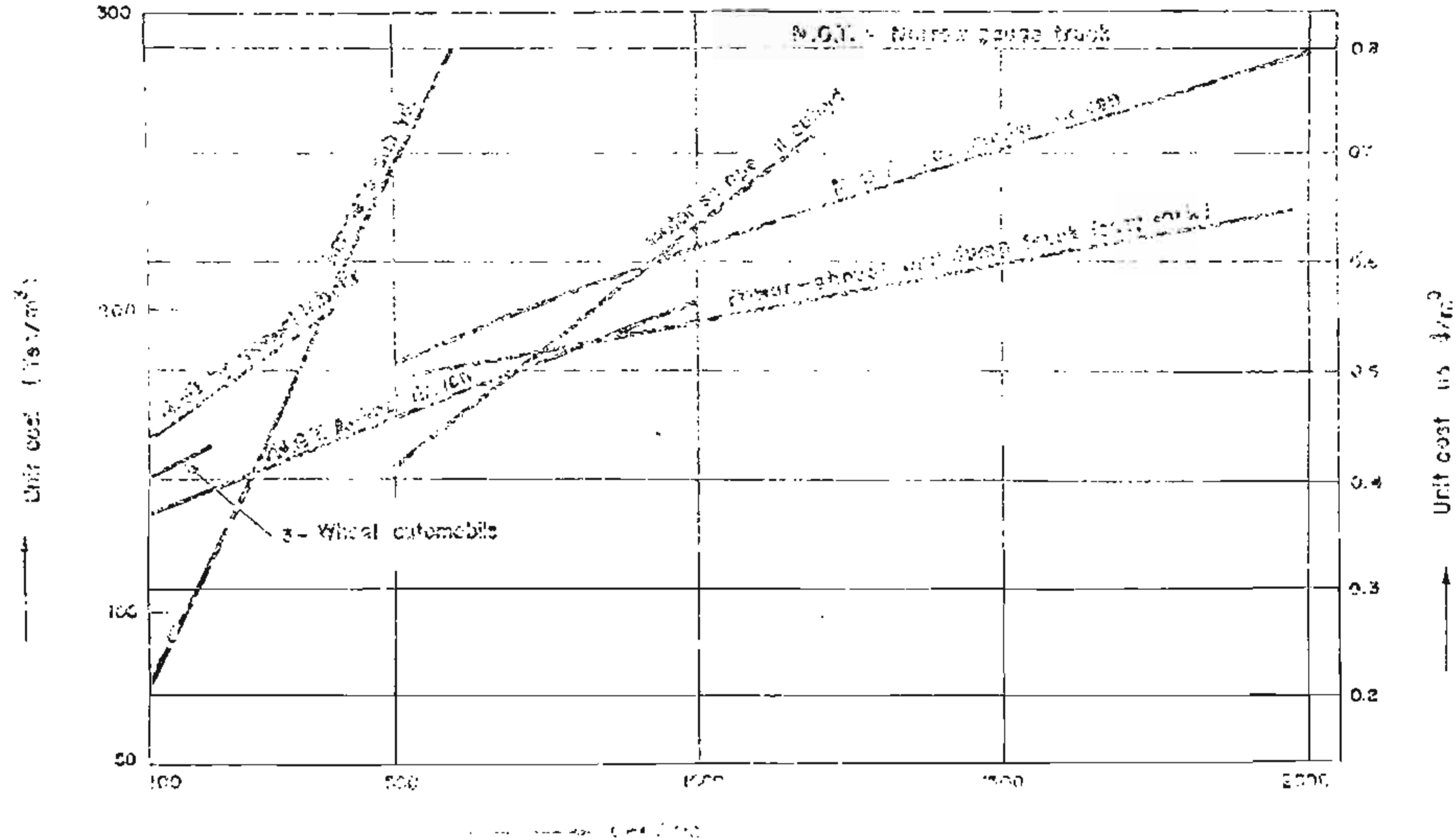


Unit cost per m3 Yen/m3. $/m3 (common soil)
N.G.T. = Narrow gaug Truck
Manual labour
Rubber tire wagon
Bulldozer
3 Wheel automobile
N.G.T. by manual labour
N.G.T. Animal driven
Scraper
Unit cost (Yen/m3)
Unit cost us. $/m3
Lead (m)
200
150
100
50
20
0.5
0.4
0.3
0.2
0.1
0
20
40
60
80
100
120
140
160
180
200

GRAPH — 3

Unit cost per m^3

Yen/m^3 $/$m^3$ (common soil)



GRAPH – 4

Comparision of output per hour perman lead = 10 to 200 m