SECTION 12B

EARTHMOVING DATA

CONTENTS

SOIL CLASSIFICATION FOR EARTH-MOVING OPERATIONS

Various classifications have been established properly for soil depending on the purposes of earth-moving operations. Generally speaking, however, detailed classifications of soil are not required for the ordinary earth-moving operations.

Rather, attention is required to be given as to whether the soil to be handled is of special ores or contains special clay minerals.

Hereinafter is described the knowledge necessary for earth work planning prior to such operations as digging, loading, hauling, pushing (spreading), rolling compaction, etc. on ordinary terrains.

* Datas (figures) to be given hereinafter vary largely depending on various operating and environmental conditions. Consequently, before starting the earth work, tests should be conducted to obtain correct data for operations.

The most basic soil classification depends on the sizes of particles contained in the soil. Normally, these particles are different in size and called, for example, "Silty sand".

COMMON NAME	PARTICLE DIAMETERS (Millimeters)	SPECIFIC WEIGHT (Bank) (T/M^3)
GRAVEL	2.0 ~ 50.0	
Crushed		1.70 ~ 1.80
Round		1.80 ~ 1.90
SAND	0.05 ~ 2.0	
Dry		1.40 ~ 1.50
Damp		1.65 ~ 1.75
Wet		1.80 ~ 1.90

SILT & CLAY	0.001 ~ 0.05	
Dry		1.60 ~ 1.80
Wet		1.90 ~ 2.10
STONE, CRUSHED	50.0 up	1.55 ~ 1.65
EARTH	mixed	
Dry		1.50 ~ 1.60
Wet		1.60 ~ 1.70

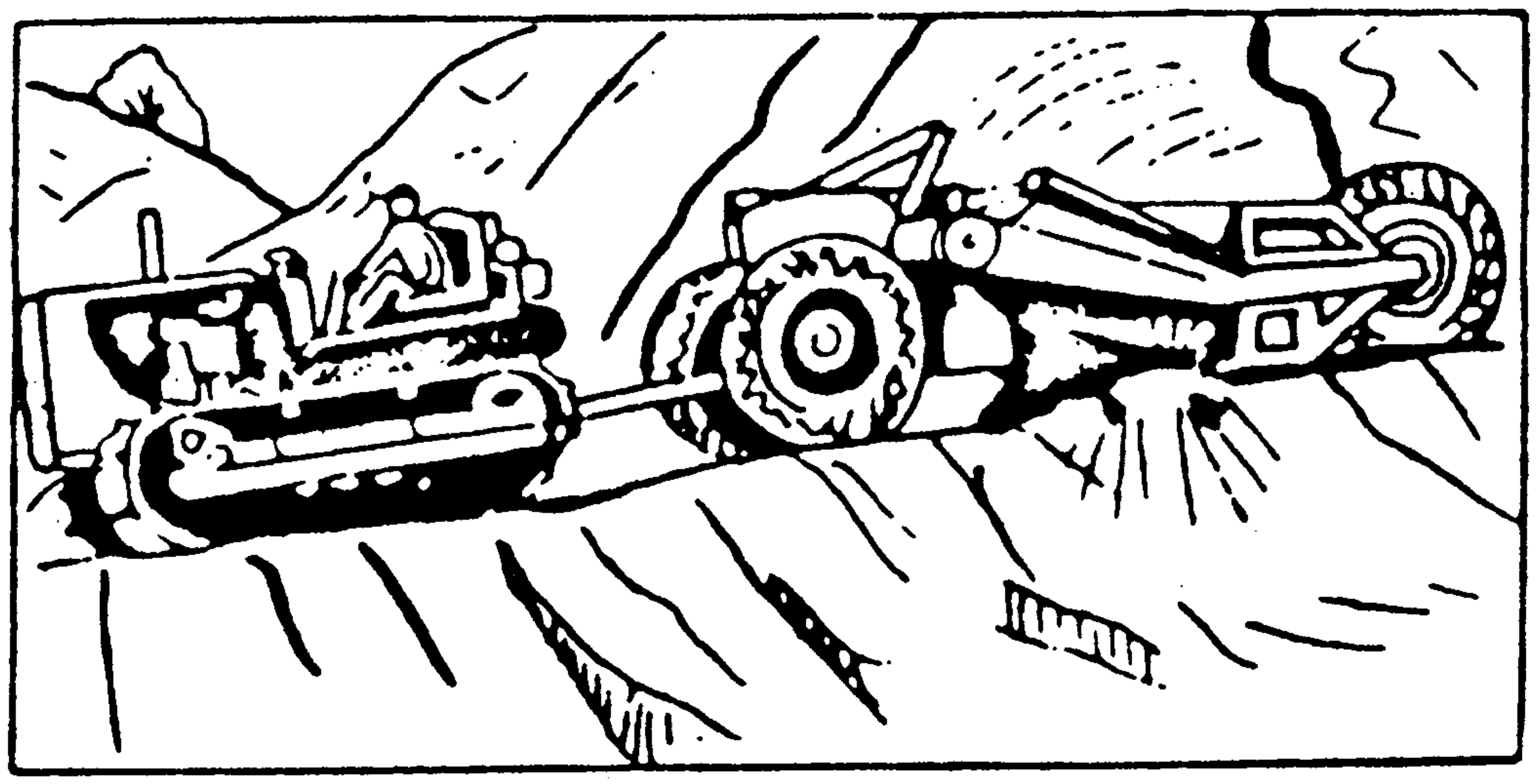
Some knowledge of the weight data per unit volume of materials or their major ingredients is important for their handling or hauling in mines, etc. The specific weight data of some major types of soil and ingredients are given below.

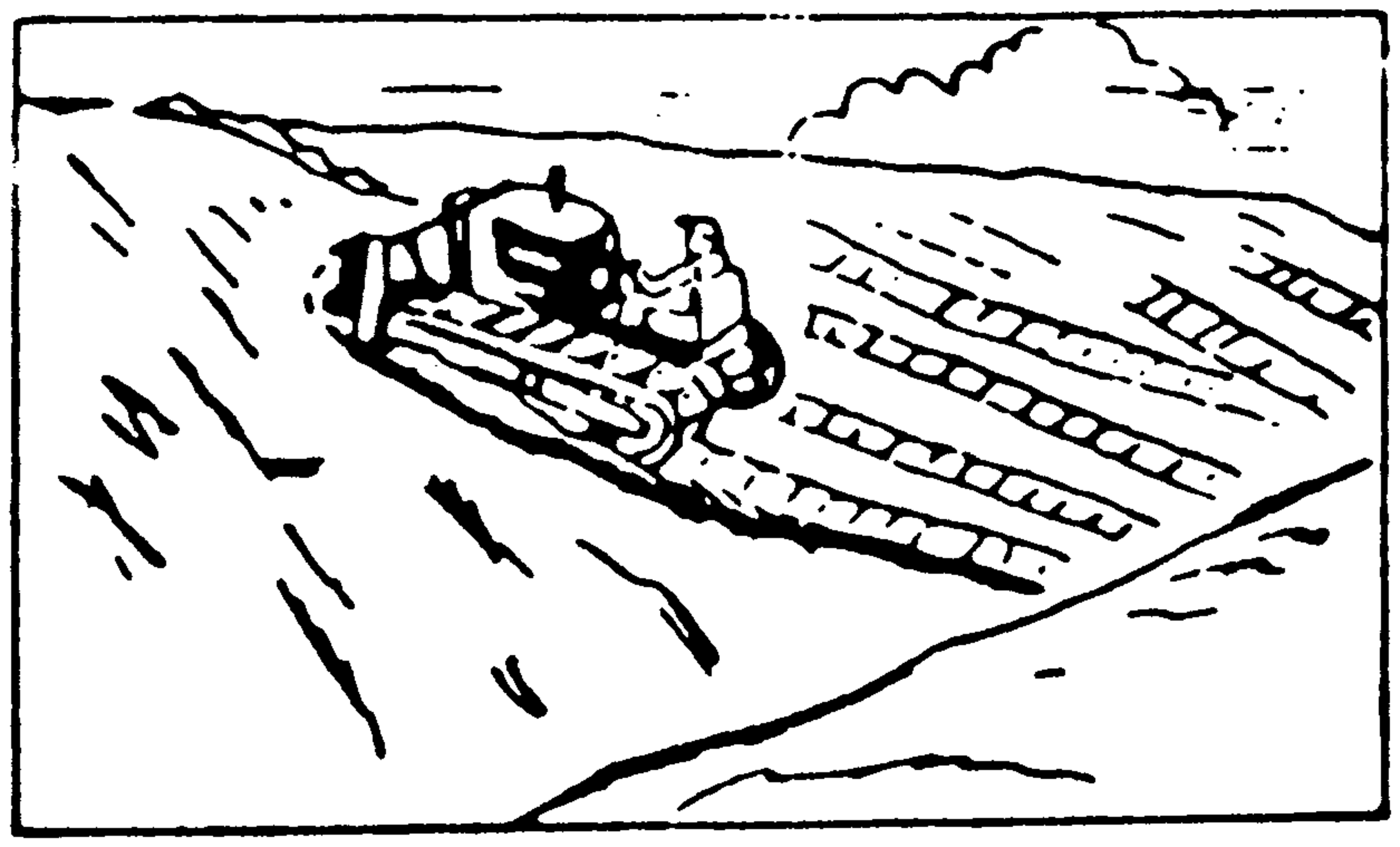
Material	SPECIFIC Weight (T/M^3) Bank	Crushed (Loose)
Basalt	2.70 ~ 3.00	1.60 ~ 1.70
Coal	–	0.40 ~ 0.60
Granite	2.50 ~ 2.80	1.40 ~ 1.50
Limestone	2.30 ~ 3.00	~ 2.00
Sand Stone	2.00 ~ 2.80	1.30 ~ 1.50
CaLiche	2.00 ~ 2.20	1.40 ~ 1.50
Cinders	–	0.60 ~ 0.70
Gypsum	2.30 ~ 2.40	1.50 ~ 1.70
Peat Dry	0.60 ~ 0.70	0.40 ~ 0.50
Wet	1.80 ~ 2.00	1.10 ~ 1.20
Slag	–	1.80
Trap Rock	2.50 ~ 2.70	1.60 ~ 1.80
Snow Dry	0.10 ~ 0.20	–
Wet	0.40 ~ 0.60	–
Rock Salt	2.10 ~ 2.60	~ 1.80
Iron Ore 60%	4.80	–
40%	3.20	–

HAULING PERFORMANCE OF CONSTRUCTION MACHINES

INTRODUCTION

"What Model or type of a tractor is most suitable to pull this trailer?" "Is this bulldozer capable of going up this hill while pulling that scraper loaded full?"
In order to give explicit answers to these questions, it is necessary to have the right understanding of the hauling performance of vehicles.





For easy understanding, let us explain the hauling performance with the following machine capabilities and related elements.

[1]	The inherent machine capability
[2]	Elements limiting the inherent machine capability
[3]	Machine capabilities required for earthmoving operations

INHERENT MACHINE CAPABILITY

1 What is the inherent machine capability?

(a) Output power

The engine horsepower of a construction machine is the most essential power of those developed by the machine itself. This can be estimated by multiplying one element (tractive force) by another element (a travel speed). Accordingly, where the engine of a machine develops a rated power; the smaller the travel speed, the larger the tractive force or drawbar pull will be. On the contrary, the larger the travel speed, the smaller the drawbar pull.

(b) Gear-shifting

Gear-shifting is effected to determine the optimum drawbar pull and travel speed required for accomplishing a given job. Therefore, a machine has several gears to be selected by shifting for the optimum travel speed.

2 Direct-drive type tractor

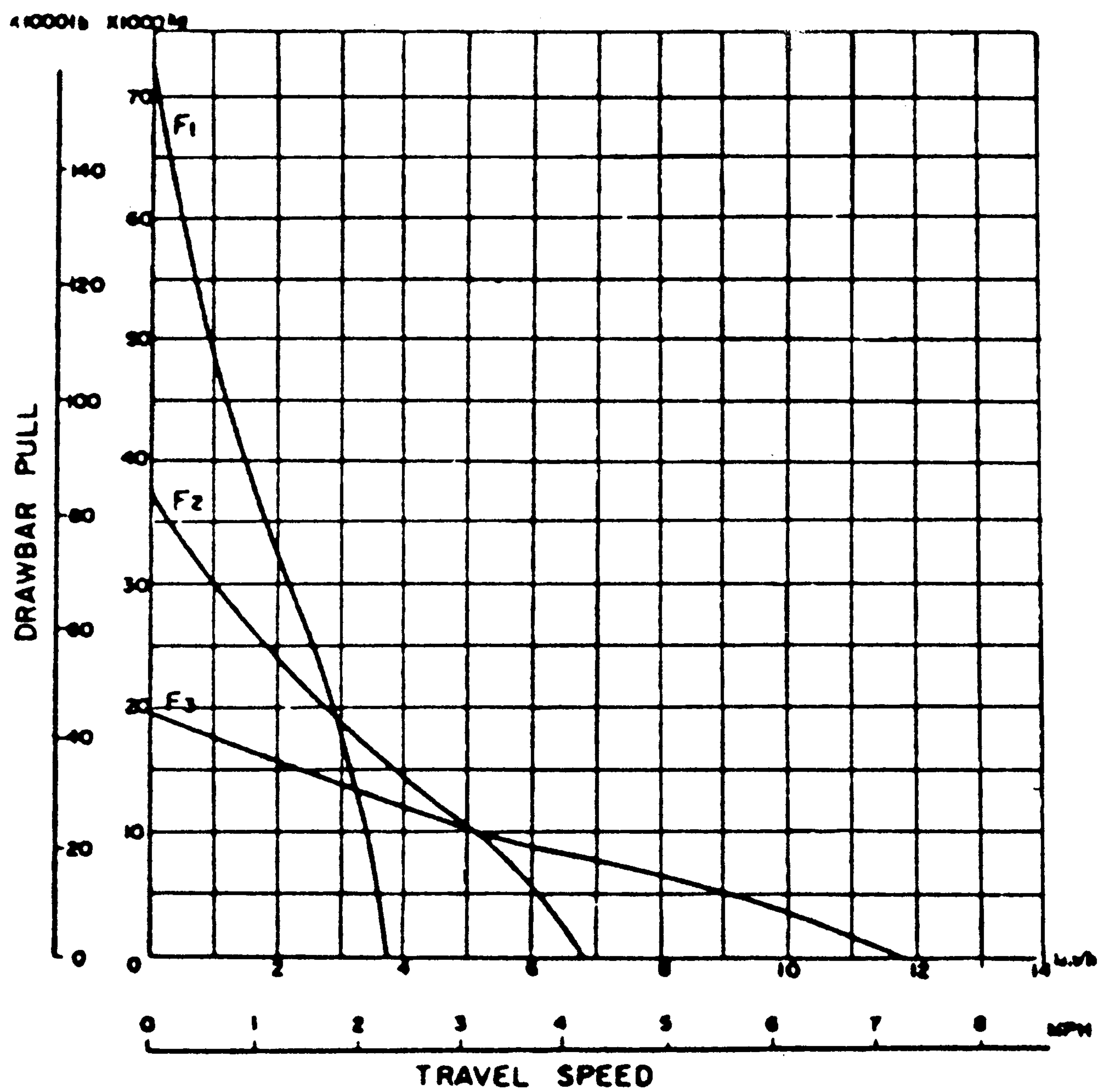
The table below gives the drawbar pull and travel speeds of a direct-drive type bulldozer.

Gear-shifting	Travel speed km/h	Rated drawbar pull kg	Max. drawbar pull kg
F1	2.5	27600	34500
"2	3.5	19700	–
"3	4.9	14100	–
"4	6.4	10780	–
"5	8.9	7670	–
"6	12.9	5350	–

The rated drawbar pull is such a tractive force that can be developed at the rated engine power and the rated revolutions (rpm). The rated drawbar pull is normally estimated by taking into account the travelling resistance (which will be explained later) and the mechanical loss of power in its line from the engine to the sprockets.
The maximum drawbar pull is the maximum tractive force that can be developed by a machine and is estimated from the maximum engine torque. In other words, the maximum drawbar pull of a machine can be developed by the lugging ability of its prime-mover and is practically obtained in a low gear. Consequently, the maximum drawbar pull is shown only at F1 on the specifications.

3 TORQFLOW-drive type tractor

In a TORQFLOW-drive type tractor, the relationships between the travel speeds and drawbar pull are obtained from the combined performance between the engine and the torque converter.
In a TORQFLOW-drive machine, it is difficult to relate both the drawbar pull and travel speeds directly to the engine revolutions. Thus, the hauling performance is indicated by curves. The graph below gives the hauling performance curves of the TORQFLOW-drive type bulldozer.



ELEMENTS LIMITING THE INHERENT MACHINE CAPABILITY

1 What are the elements limiting the inherent machine capability or power? These are;

(a) Traction between the undercarriage (tracks or wheels) and the road surface.

(b) Altitude

Altitude in (b) will be described in a separate issue and herein is examined the problem of traction between the undercarriage and the road surface.

2 Traction between the undercarriage and road surface

"When a motor vehicle cannot be moved due to the slipping on the snow-covered road, what should be done to move the vehicle?"

The answers are;

	Solution		Reason
(1)	Add load to the driving wheels.	⇨	The tractive force is increased by the added load.
(2)	Chain the wheel tires or replace the tires with the spiked type.	⇨	The undercarriage is made so as to develop more traction.
(3)	Scatter sand or spread straw-mats on the road surface.	⇨	The critical tractive force is increased by the higher coefficient of traction.

The above facts can also be applied to a crawler tractor. Now, let us see the coefficient of cohesion and the critical tractive force or traction used in the above table. The critical traction is the maximum traction available depending on the cohesive condition of the road surface. This can be estimated by the following formula.

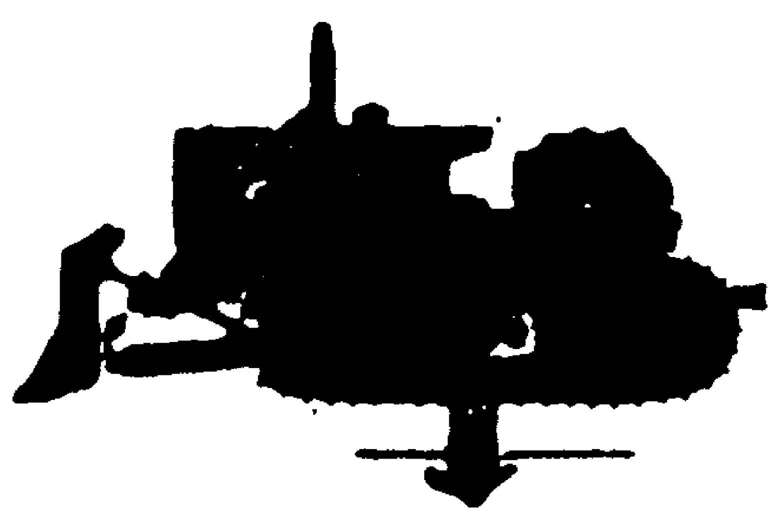
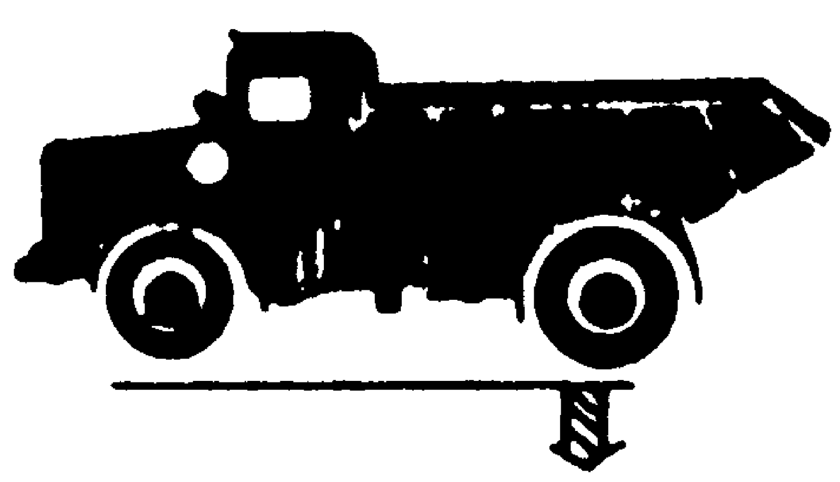
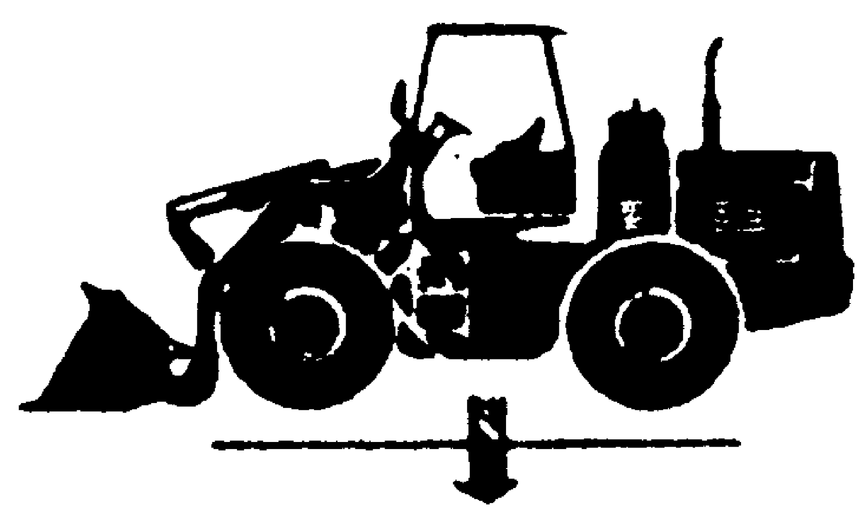
$$Fd = \mu d \cdot Gd$$

Where, Fd: Critical traction (kg)
μd: Coefficient of traction
Gd: Weight imposed on the driving wheels (kg)

The coefficient of traction depends on the condition of the road surface. Any applicable coefficient of traction can be selected from among those given in the table below.

	Tractor w/pneumatic tires	Crawler tractor
Dry concrete	0.95	0.45
Dry macadam road	0.70	
Wet macadam road	0.65	
Dry unpaved plain road	0.60	0.90
Dry ground	0.55	0.90
Wet ground	0.45	0.85
Dry loose terrain	0.40	0.60
Loose gravel	0.36	0.25
Loose sand	0.27	0.30
Muddy ground	0.25	0.25
Packed snow	0.20	0.15
Ice	0.12	0.12

Weight to be imposed on the driving wheels can be determined by referring to the table below.

Crawler type tractor	2-wheel drive tractor	4-wheel drive tractor
		
Total weight of tractor	Weight imposed on the driving wheels	Total weight of tractor

Example (1)	Assume that the D155 tractor pulling a towed compactor must do compaction in a dry, loose terrain. What is the critical drawbar pull?

Solution: The operating weight of the D155 tractor is 26730 kg. Then, Fd = 0.60 x 26730 = 16040 kg.

Example (2)	What are the values of the drawbar pull which the D50A-15 bulldozer can develop at F1 and F2 in a dry, loose terrain?

Solution: The operating weight of the D50A-15 bulldozer is 11400 kg. Its critical drawbar pull is 11400 x 0.60 = 6840 kg. The rated drawbar pull indicated in its specifications is 8280kg at F1 or 5920 kg at F2.

Consequently,

at F1: The rated drawbar pull is 8280 kg, but the tracks will start shoe slip at the drawbar pull beyond 6840 kg, making it impossible ibl for its drawbar pull to be utilized to the full. Thus, the critical drawbar pull practically available is 6840 kg.

at F2: The rated drawbar pull is 5920 kg. Thus, the drawbar pull can be utilized to the full.

MACHINE CAPABILITIES REQUIRED FOR EARTH-MOVING OPERATIONS.

1 What are the elements limiting the machine capabilities required for earthmoving operations?
When a truck is traveling on the road or going uphill, the following phenomena will be encountered as a matter of course.

Phenomenon		Influential element
(1) The travel speed of a truck with load on the flat road should vary when the same truck with the same load travels on the rugged or rutted surface.	⇨	Rolling resistance
(2) When traveling on the flat road or going uphill in the same operating gear, the travel speed should vary as a matter of course.	⇨	Grade resistance

2 Rolling resistance

When a vehicle is traveling on the ground or road, the regarding force of ground against wheels or tracks should take place. Such a resistance varies depending on the ground or road surface conditions.
The rolling resistance is measured in the ratio to the vehicle weight and can be estimated by the following formula.

$$Wr = \mu r.G$$

Where, Wr: Rolling resistance (kg)
μr : Coefficients of rolling resistance
G : Vehicle operating weight

The coefficient of rolling resistance can be selected from among those given in the table below, according to the ground or road surface conditions.

Type and conditions of ground	μr (%)		
	Vehicle w/iron wheel treads	Crawler tractor	Tractor w/pneumatic tired wheels
Iron truck	1.0		
Concrete floor	2.0	2.8	2.3
Macadam road	2.9	3.3	2.8
Wood pavement	2.5		
Dry unpaved plain road	4.5	4.6	3.5
Firm terrain	10.0	5.5	4.0
Dry, loose terrain	11.5	6.5	4.5
Soft terrain	16.0	8.0	9.0
Loose gravel	15.0	9.0	12.0
Loose sand	15.0	9.0	12.0
Muddy ground		12.0	16.0
Packed snow			3.7
Ice			2.0

In a crawler tractor, too, the rolling resistance should vary depending on the type of applied soil. The representative values of rolling resistance, however, are taken into account in preparing the curves for drawbar pull and hauling performance of crawler tractors. Therefore, the varying rolling resistance may practically be ignored.

Example (3) **What is the rolling resistance of the D85-12 tractor to pull the RS12 scraper (empty). The ground surface is in a soft terrian.**

Solution: The weight of an RS12 scraper (empty) is 10500 kg.
The rolling resistance = 0.09 x 10500 = 945 kg

Example (4) **What is the rolling resistance of the D155 tractor to pull the RS24 scraper loaded full. The ground surface is in a dry, loose terrain.**

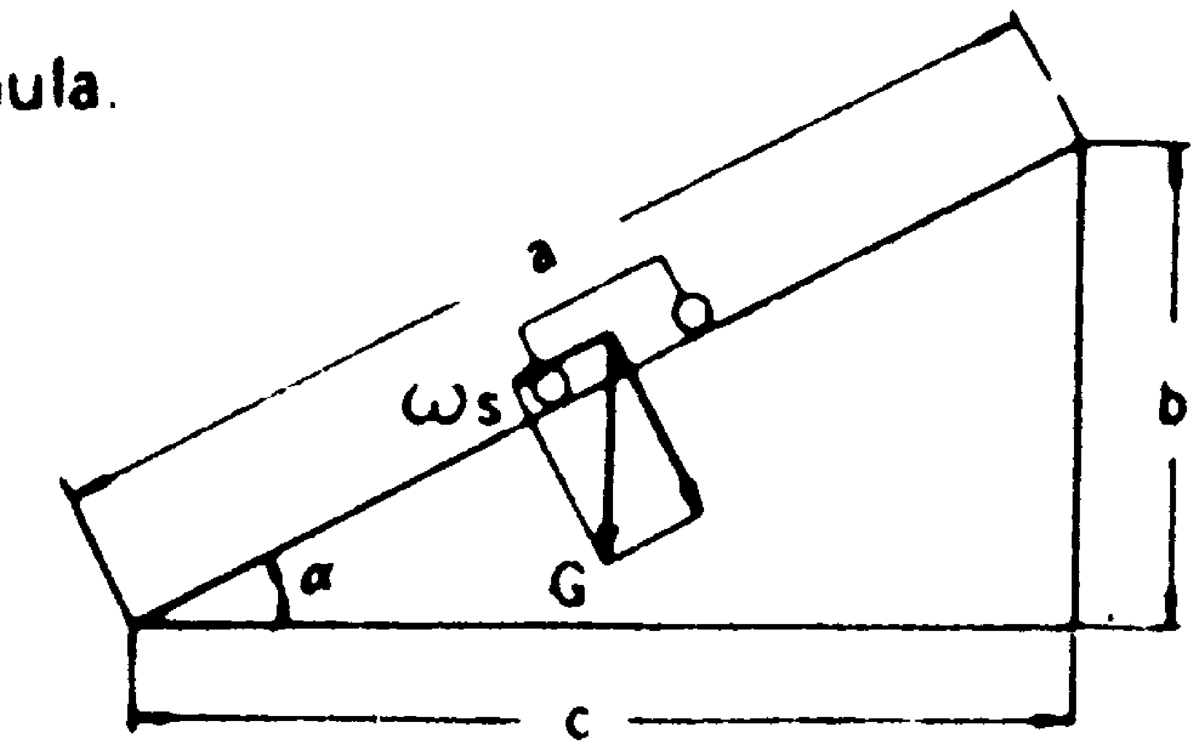
Solution: The net weight of an RS24 is 18000 kg.
The max. pay load is 34080 kg
The gross weight is 52080 kg.
Thus, the rolling resistance = 0.045 x 52080 = 2340 kg

3 Grade resistance

The grade resistance is the retarding force of gravity to be encountered when a vehicle is going uphill.
The grade resistance can be estimated by the following formula.

$$W_s = G \cdot \sin \alpha$$

Where, Ws: Grade resistance (kg)
G : Operating weight of a vehicle (kg)
α : Angle formed with the horizon (degree)



A grade (degree) and sinα can be selected from among those given in the table below.

Grade resistance (%) converted from angle (°) of gradient

Angle	% (sin α)	Angle	% (sin α)	Angle	% (sin α)
1	1.8	11	19.0	21	35.8
2	3.5	12	20.8	22	37.5
3	5.2	13	22.5	23	39.1
4	7.0	14	24.2	24	40.2
5	8.7	15	25.9	25	42.3
6	10.5	16	27.6	26	43.8
7	12.2	17	29.2	27	45.4
8	13.9	18	30.9	28	47.0
9	15.6	19	32.6	29	48.5
10	17.4	20	34.2	30	50.0

Example (5) What is the grade resistance against the D50A-15 angledozer going uphill at 15°?

Solution: The operating weight of the D50A-15 angledozer is 11400 kg. Thus, the grade resistance will be 11400 x 0.259 = 2950 kg.

4 Hauling resistance

The hauling resistance is the grand total of the rolling resistance, grade resistance, accelerating resistance and air resistance. However, construction machines are slow in the travel speed. Normally, the hauling resistance of construction machines may be considered to be the total of the rolling resistance and grade resistance.
The grade resistance acts so as to retard the uphill traveling of a vehicle, whereas the grade resistance acts so as to accelerate the downhill traveling. The above relationships can be indicated as follows:

Conditions	Hauling resistance
Uphill traveling	Rolling resistance + grade resistance
Traveling on flat, level surface	Rolling resistance.
Downhill traveling	Rolling resistance − grade resistance

Example (6) What is the hauling resistance against the D60−6 tractor going uphill at 4° in a dry, loose terrain, while pulling an RS08 scraper with max. load?

Solution: The gross weight of the RS08 with max. load is 18870 kg.
The rolling resistance factor is 0.045. Thus, the rolling resistance is
0.045 x 18870 = 850 kg
The weight of the D60-6 tractor is 12550 kg.
The gross weight of the RS08 is 18870 kg.
Then, the total weight of both machines is 31420 kg.
Consequently, the grade resistance is 0.07 x 31420 ≈ 2200 kg.
Thus, the hauling resistance is 850 + 2200 = 3050 kg.

SUMMARY AND APPLICATION

1 Summary

Capabilities required for earthmoving operations
(Hauling resistance (rolling resistance + grade resistance) should be estimated.)

Inherent machine capability (drawbar pull and travel speed in each gear should be examined from the specification sheet of a machine)

Applicability of a machine should be checked by examining the ground surface conditions and determining the critical drawbar pull.

The optimum machine meeting the drawbar pull required for an earthmoving operation should be selected on the basis of the inherent drawbar pull and travel speeds peculiar to the machine.
At the same time, the optimum operating gear should be determined.

2 Application

Example (7)	Assume that the D65 tractor is used to pull a wheeled wagon (the empty weight: 17 tons) with a 50-ton load in a dry, loose terrain. What are the operating gears and the corresponding approx. travel speeds available on a flat, level ground? What is the degree of a hill climable under the same conditions?

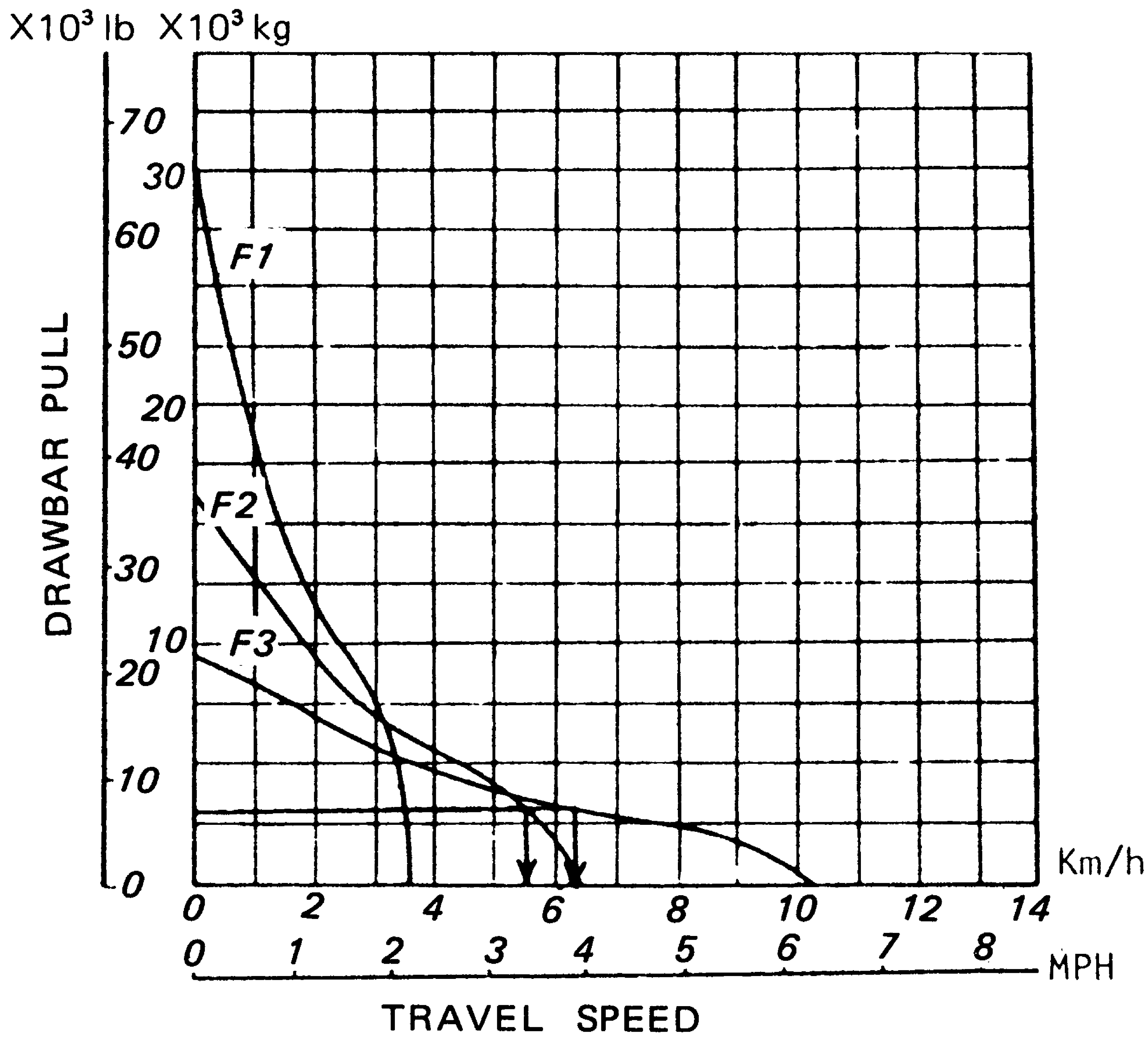
Solution: The rolling resistance

Weight of the wagon (empty): 17000 kg
Pay load: 50000 kg
Total weight: 67000 kg
Coefficient of rolling resistance: 0.045

Consequently, the rolling resistance against the wagon is 67000 x 0.045 = 3015 kg

Operating gears and travel speeds on flat, level ground

From the hauling performance curves below, the operating gears and travel speeds at a 3015-kg drawbar pull are;
approx. 6.2 km/h at F3 or
approx. 4.7 km/h at F2



Critical drawbar pull

The operating weight of D65 tractor: 12750 kg
Coefficient of traction: 0.60
Consequently, the critical drawbar pull is 12750 x 0.60 = 7650 kg

Degree of a climable hill (gradeability)

Tractor weight + wagon weight + pay load = 12750 + 17000 + 50000 = 79750 kg

The grade resistance retarding per angle of grade is 79750 x 0.018 = 1435 kg

Consequently,

$$\text{Gradeability } \left(\frac{\text{Critical drawbar pull} - \text{rolling resistance}}{\text{Grade resistance per angle of grade}}\right)$$

$$\text{will be } \frac{7650 - 3015}{1435} = 3.2 \text{ (degree)}$$

The explanations made so far on the travelling or hauling performance of construction machines pertain only to the traveling of individual machines and the pulling of towed vehicles by tractors. For an instance where a tractor pulls a scraper, it will be judged whether the tractor can be used for this purpose, but it will not be determined whether the tractor can perform a digging or a loading operation under the same conditions as mentioned above. Operators or field-superintendents are requested to keep it in mind that such a judgement should be based on the operators' accumulated experiment or on the references for such operating combinations or cooperation among towing tractors and towed vehicles as recommended by KOMATSU.

TRAFFICABILITY

Operating efficiency of a construction machine depends largely on the ground surface on which the machine travels. In a clay, loam or clayey soil high in water or moisture content, the bearing force of soil is low and a "kneading" phenomenon is liable to occur. Consequently, there is such a case where a construction machine cannot be operated because of the type and conditions of soil. The degree of the traveling capabiity of a construction machine is called the trafficability.

In general, trafficability is indicated by a cone index No. (The method of measuring a cone index No. will be described later.)

The larger the cone index No. becomes, the higher the trafficability of the machine will become. In other words, on the soil larger in cone index No., a construction machine will be able to travel easier.

The minimum cone index numbers required for various types of construction machines to perform digging, hauling operations, etc. are given below.

Cone index No.	Type of construction machine	Ground pressure (kg/cm²)
Below 2	Ultra swamp bulldozer (PL class)	0.15 ~ 0.25
2 to 4	Swamp bulldozer (P Class)	0.2 ~ 0.3
4 to 5	Small-size bulldozer (D10 ~ D31)	0.3 ~ 0.6
5 to 7	Medium-size bulldozer (D50 ~ D75S)	0.6 ~ 0.8
7 to 10	Large-size bulldozer (D80 ~ D455) & towed scraper	0.7 ~ 1.3
10 to 13	Motor scraper	
15 & more	Dump truck	

NOTE: In determining a cone index, apply the cone-penetrometer at 3 or 4 points at least to average the variations in the measured values.

*Cone index numbers (qc)

A cone index No. is measured by means of a cone penetrometer in a cone penetration test.
A rod with a cone at the tip is pushed into the soil by hand.
The pressure required to advance the cone at a slow constant rate is known as the penetration resistance.
The penetration resistance is read out on the dial gauge.
Thereby, the shearing strength of soil can be estimated.
Then, a cone index No. can be obtained by referring the estimated shearing strength to the conversion table attached to the meter.