SECTION **14A**

PRODUCTIVITY

CONTENTS

When planning mechanized projects, one extremely important issue is how to calculate the production of the machines.

The first step when estimating the production is to calculate a theoretical value as explained below. This theoretical value is then adjusted according to actual figures obtained from past experience in similar operations.

On the basis of these figures (particularly those for job efficiency) it will be possible to determine values suitable for the project which will be neither over-optimistic nor wasteful.

Therefore it is first necessary to fully understand the theoretical calculations and to be able to obtain a figure for working efficiency which is feasible on that job site.

From this it is possible to obtain a realistic figure for the work volume that can be attained.

Method of calculating production

It is usual to express the production of construction machines in terms of production per hour (m^3/h or cu.yd./h).

This is basically calculated from the haul volume per cycle, and the number of cycles.

$$Q = q \times N \times E = q \times \frac{60}{Cm} \times E$$

where Q : Hourly production (m^3/hr; yd^3/hr)

q : Production (m^3; yd^3) per cycle, of loose, excavated soil (This is determined by the machine capacity.)

N : Number of cycles per hour = $\frac{60}{Cm}$

Cm : Cycle time (in minutes)

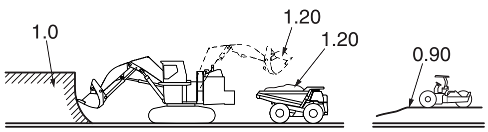
E : Job efficiency (see the item 2)

1. Earth volume conversion factor (f)

The volume of any amount of earth depends on whether the soil is in its natural ground condition (that is, unexcavated), whether it is loose, or whether it has been compacted.

This conversion factor depends on the type of soil and the operating state, but as a general rule, the values in the following table are used.

To obtain only the productivity of a construction machine, the earth volume conversion factor is taken as Table 1 and machine productivity is expressed in terms of loose earth. However, when planning actual projects, work volume is calculated in terms of unexcavated earth or compacted earth, so care must be taken to convert these figures.



Changes in earth volume

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Example:

1,000 m^3 of unexcavated earth has to be hauled.

a) What will its volume be when it has been excavated ready for hauling?

b) What will its volume be if it is then compacted?

	Unexcavated volume		Loose volume		Compacted volume
Ordinary soil :	**1,000 m^3**	**× 1.25 =**	**1,250 m^3**	**→ 1,250 × 0.72 =**	**900 m^3**
Gravel :	**1,000 m^3**	**× 1.13 =**	**1,130 m^3**	**→ 1,130 × 0.91 =**	**1,030 m^3**
Soft rock :	**1,000 m^3**	**× 1.65 =**	**1,650 m^3**	**→ 1,650 × 0.74 =**	**1,220 m^3**

Earth volume conversion factor (f) (applies to the factors 1.25, 1.13, 1.65 and 0.72, 0.91, 0.74)

Table 1 Earth volume conversion factor (f)

Nature of earth	Initial	Conditions of earth to be moved		
		Bank condition	Loosened condition	Compacted condition
Sand	(A) (B) (C)	1.00 0.90 1.05	1.11 1.00 1.17	0.95 0.86 1.00
Sandy clay	(A) (B) (C)	1.00 0.80 1.11	1.25 1.00 1.39	0.90 0.72 1.00
Clay	(A) (B) (C)	1.00 0.70 1.11	1.43 1.00 1.59	0.90 0.63 1.00
Gravelly soil	(A) (B) (C)	1.00 0.85 0.93	1.18 1.00 1.09	1.08 0.91 1.00
Gravel	(A) (B) (C)	1.00 0.88 0.97	1.13 1.00 1.10	1.03 0.91 1.00
Solid or rugged gravel	(A) (B) (C)	1.00 0.70 0.77	1.42 1.00 1.10	1.29 0.91 1.00
Broken limestone, sandstone and other soft rocks	(A) (B) (C)	1.00 0.61 0.82	1.65 1.00 1.35	1.22 0.74 1.00
Broken granite, basalt and other hard rocks	(A) (B) (C)	1.00 0.59 0.76	1.70 1.00 1.30	1.31 0.77 1.00
Broken rocks	(A) (B) (C)	1.00 0.57 0.71	1.75 1.00 1.24	1.40 0.80 1.00
Blasted bulky rocks	(A) (B) (C)	1.00 0.56 0.77	1.80 1.00 1.38	1.30 0.72 1.00

(A) Bank condition (B) Loosened condition (C) Compacted condition

2. Job efficiency (E)

When planning a project, the hourly productivity of the machines needed in the project is the standard productivity under ideal conditions multiplied by a certain factor. This factor is called job efficiency.

Job efficiency depends on many factors such as topography, operator's skill, and proper selection and disposition of machines. Time out of an hour machine use is actually used.

It is very difficult to estimate a value for job efficiency due to the many factors involved. Therefore, efficiency is given in the following section as a rough guide.

BULLDOZERS

(DOZING)

The hourly production of a bulldozer when excavating or dozing can be obtained by using the following fomula:

$$Q = q \times \frac{60}{Cm} \times e \times E$$

where Q : Hourly production (m^3 /hr; yd^3/hr) q : Production per cycle (m^3; yd^3)
Cm : Cycle time (in minutes) e : Grade factor
E : Job efficiency

1. Production per cycle (q)

For dozing operations, the production per cycle is theoretically calculated as follows:

$q = q_1 \times a$ q_1 : Blade capacity (m^3; yd^3) a : Blade fill factor

When calculating the standard productivity of a bulldozer, the figure used for the volume of earth hauled in each cycle, was taken as blade capacity. In fact, production per cycle differs with the type of soil, so the blade fill factor is used to adjust this figure. See Table 2 to select the factor.

Table 2 Blade Fill Factor (a)

Dozing conditions		Blade fill factor (a)
Easy dozing	Full blade of soil can be dozed as completely loosened soil. Low water contented, no-compacted sandy soil, general soil, stockpile material.	1.1 ~ 0.9
Average dozing	Soil is loose, but impossible to doze full blade of soil. Soil with gravel, sand, fine crushed rock.	0.9 ~ 0.7
Rather difficult dozing	High water content and sticky clay, sand with cobbles, hard dry clay and natural ground.	0.7 ~ 0.6
Difficult dozing	Blasted rock, or large pieces of rock	0.6 ~ 0.4

2. Cycle time (Cm)

The time needed for a bulldozer to complete one cycle (dozing, reversing and gear shifting) is calculated by the following formula:

$$Cm\ (min.) = \frac{D}{F} + \frac{D}{R} + Z$$

where D : Haul distance (m; yd) F : Forward speed (m/min.; yd./min.)
R : Reverse speed (m/min.; yd./min.) Z : Time required for gear shifting (min.)

(1) Forward speed/reverse speed

As a rule a speed range of 3-5 km/h for forward, and 5-7 km/h for reverse should be chosen.

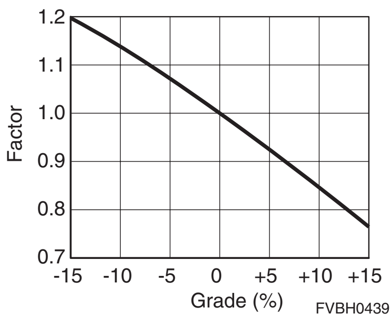
(2) Time required for gear shifting

	Time required for gear shifting
Direct-drive type	0.10 min.
TORQFLOW (Torque converter type)	0.05 min.

3. Grade factor (e)

Production is affected by the grade of the ground when dozing.

The grade factor can be selected in the right hand side graph.



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4. Job efficiency (E)

The following table gives typical job efficiency as a rough guide. To obtain the actual production figure, determine the efficiency in accordance with actual operating conditions. Time out of an hour machine use is actually used.

Operating conditions	Job efficiency
Good	0.83
Average	0.75
Rather poor	0.67
Poor	0.58

(RIPPING)

Ripping production varies greatly according to such conditions as the properties of the rock, the method of operation, and the operator's skill. Therefore, it is difficult to estimate. However, from available data, the relationship as shown on the ripper section can be seen between seismic velocity and production.

(RIPPING AND DOZING)

In normal ripping operations, ripping and dozing operations are carried out repeatedly in turn. The combined production for ripping and dozing operations is calculated using the following formula.

$$Q = \frac{QR \times QD}{QR + QD}$$

Where Q = Ripping and dozing production (m^3/hr ; yd^3/hr)

QR = Ripping production (m^3/hr ; yd^3/hr)

QD = Dozing production (m^3/hr ; yd^3/hr)

When making the calculation, it is necessary to use the same unit (natural rock position, loose rock condition, soil condition) for production QR and QD.

DOZER SHOVELS AND WHEEL LOADERS

(LOADING)

Generally, the hourly production can be obtained by using the following formula:

$$Q = q \times \frac{60}{Cm} \times E$$

where Q : Hourly production (m^3/hr; yd^3/hr) q : Production per cycle (m^3; cu.yd^3)
Cm : Cycle time (min.) E : Job efficiency

1. Production per cycle (q)

$$q = q_1 \times K$$

Where q_1 : The heaped capacity given in the specifications sheet
K : Bucket fill factor .... The actual volume in the bucket differs depending on the type of loading material.
Bucket fill factor is used for that reason.

(1) Bucket fill factor

Table 3 Bucket fill factor

Loading condition	Wheel loader	Dozer shovel
A : Easy loading	1.0 ~ 1.1	1.0 ~ 1.1
B : Average loading	0.85 ~ 0.95	0.95 ~ 1.0
C : Rather difficult loading	0.8 ~ 0.85	0.9 ~ 0.95
D : Difficult loading	0.75 ~ 0.8	0.85 ~ 0.9

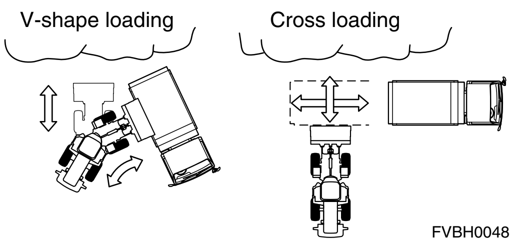
Table 4 Loading conditions

Operation conditions		Remarks
Easy loading (A)	Loading from a stockpile or from rock excavated by another excavator, bucket can be filled without any need for digging power. Sand, sandy soil, with good water content conditions.	• Loading sand or crushed rock products • Soil gathering such as loading of soil dozed by a bulldozer.
Average loading (B)	Loading of loose stockpiled soil more difficult to load than category A but possible to load an almost full bucket. Sand, sandy soil, clayey soil, clay, unscreened gravel, compacted gravel, etc. Or digging and loading of soft soil directly in natural ground condition.	Digging and loading of sandy natural ground.
Rather difficult loading (C)	Difficult to load a full bucket. Small crushed rock piled by anther machine. Finely crushed rock, hard clay, sand mixed with gravel, sandy soil, clayey soil and clay with poor water content conditions.	Loading of small crushed rock
Difficult loading (D)	Difficult to load bucket, large irregular shaped rocks forming big air pockets. Rocks blasted with explosives, boulders, sand mixed with boulders, sandy soil, clayey soil, clay, etc.	Loading of blasted rock

2. Cycle time (Cm)

The following tables show the standard cycle time according to loading method and operating conditions.

It is possible to shorten a cycle time still more than the standard cycle time by minimizing moving distance.



(1) V-shape loading

Table 5 Average cycle time for wheel loader

Unit: min.

Loading conditions \ Bucket size		~ 3 m^3	3.1 ~ 5 m^3	5.1 m^3 ~
A	Easy	0.45	0.55	0.65
B	Average	0.55	0.65	0.70
C	Rather difficult	0.70	0.70	0.75
D	Difficult	0.75	0.75	0.80

Table 6 Average cycle time for dozer shovel

Unit: min.

Loading conditions \ Bucket size		~ 3 m^3	3.1 ~ 5 m^3
A	Easy	0.55	0.60
B	Average	0.60	0.70
C	Rather difficult	0.75	0.75
D	Difficult	0.80	0.80

(2) Cross loading

Table 7 Average cycle time for wheel loader

Unit: min.

Loading conditions \ Bucket size		~ 3 m^3	3.1 ~ 5 m^3	5.1 m^3 ~
A	Easy	0.40	0.50	0.60
B	Average	0.50	0.60	0.65
C	Rather difficult	0.65	0.65	0.70
D	Difficult	0.70	0.75	0.75

Table 8 Average cycle time for dozer shovel

Unit: min.

Loading conditions \ Bucket size		~ 3 m^3	3.1 ~ 5 m^3
A	Easy	0.55	0.60
B	Average	0.60	0.70
C	Rather difficult	0.75	0.75
D	Difficult	0.80	0.80

3. Job efficiency (E)

The following table gives typical job efficiency as a rough guide. To obtain the actual production figure, determine the efficiency in accordance with actual operating conditions.

Operating conditions	Job efficiency
Good	0.83
Average	0.80
Rather poor	0.75
Poor	0.70

(LOAD AND CARRY)

$$Q = q \times \frac{60}{Cm} \times E$$

where **Q : Hourly production (m^3/hr; yd^3/hr)** **q : Production per cycle (m^3; yd^3)**
Cm : Cycle time (min.) **E : Job efficiency**

1. Production per cycle (q)

$$q = q_1 \times K$$

where **q_1 : The heaped capacity given in the specifications sheet**
K : Bucket fill factor

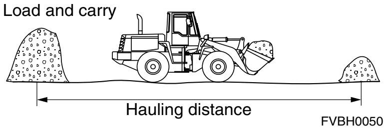
(1) Bucket fill factor

In a load and carry operation, fully heaped bucket causes soil spillage from bucket during hauling, so partially heaped bucket is recommendable.

Use a bucket fill factor of 0.7 ~ 0.9.

2. Cycle time (Cm)

$$Cm = \frac{D}{\frac{1000VF}{60}} + \frac{D}{\frac{1000VR}{60}} + Z$$



Where D : Hauling distance (m, yd)
VR: Return speed (km/hr; MPH)
VF : Travel speed with load (km/hr; MPH)
Z : Fixed time (min)

(1) Travel speed for wheel loader

Operation conditions		Speed km/hr(MPH)	
		Loaded	**Empty**
Good	Hauling on well compacted flat road, few bumps in road surface, no meeting other machines, can concentrate on L & C.	10 ~ 23 (6.2 ~ 14)	11 ~ 24 (6.8 ~ 15)
Average	Few bumps on road surface, flat road, some auxiliary work carrying large lumps of rock.	10 ~ 18 (6.2 ~ 11)	11 ~ 19 6.8 ~ 12)
Rather poor	Bumps in road surface, high rate of auxiliary work.	10 ~ 15 (6.2 ~ 9.3)	10 ~ 16 (6.2 ~ 10)
Poor	Large bumps in road, meeting other machines, difficult to carry out smooth work, large amount of auxiliary work.	9 ~ 12 (5.6 ~ 7.5)	9 ~ 14 (5.6 ~ 8.7)

(2) Fixed time (Z)

$$Z = t_1 + t_2 + t_3 + t_2$$

where Z : 0.60 ~ 0.75 (min.)
t_2 : Turning time (0.15 min.)
t_1 : Loading time (0.20 ~ 0.35 min.)
t_3 : Dumping time (0.10 min.)

3. Job efficiency (E)

The following table gives typical job efficiency as a rough guide. To obtain the actual production figure, determine the efficiency in accordance with actual operating conditions.

Operating conditions	Job efficiency
Good	0.83
Average	0.80
Rather poor	0.75
Poor	0.70

HYDRAULIC EXCAVATORS

(CONSTRUCTION APPLICATION)

$$Q = q \times \frac{3600}{Cm} \times E$$

where Q : Hourly production (m^3 /hr; yd^3 /hr) q : Production per cycle (m^3; yd^3)
Cm : Cycle time (sec.) E : Job efficiency

1. Production per cycle (q)

$$q = q_1 \times K$$

where q_1 : Bucket capacity (heaped) (m^3; yd^3) K : Bucket fill factor

(1) Bucket fill factor

The bucket fill factor varies according to the nature of material.

A suitable factor can be selected from the table, taking into consideration the applicable excavating conditions.

Table 9 Bucket fill factor (Backhoe)

~ PC2000	Excavating Conditions	Bucket fill factor
Easy	Excavating natural ground of clayey soil, clay, or soft soil	**1.1 ~ 1.2**
Average	Excavating natural ground of soil such as sandy soil and dry soil	**1.0 ~ 1.1**
Rather difficult	Excavating natural ground of sandy soil with gravel	**0.8 ~ 0.9**
Difficult	Loading blasted rock	**0.7 ~ 0.8**

Table 10 Bucket fill factor (Loading shovel)

~ PC2000	Excavating Conditions	Bucket fill factor
Easy	Loading clayey soil, clay, or soft soil	**1.0 ~ 1.1**
Average	Loading loose soil with small diameter gravel	**0.95 ~ 1.0**
Rather difficult	Loading well blasted rock	**0.90 ~ 0.95**
Difficult	Loading poorly blasted rock	**0.85 ~ 0.90**

2. Cycle time (Cm)

Cycle time = Excavating time + swing time (loaded) + dumping time + swing time (empty)

However, here we use **cycle time = (standard cycle time) × (conversion factor)**
The standard cycle time for each machine is determined from the following table.

Table 11 Standard cycle time for backhoe **Unit: sec**

Model \ Range	Swing angle 45° ~ 90°	Swing angle 90° ~ 180°	Model \ Range	Swing angle 45° ~ 90°	Swing angle 90° ~ 180°
PC78	10 ~ 13	13 ~ 16	PC270, PC290	15 ~ 18	18 ~ 21
PW140	11 ~ 14	14 ~ 17	PC300, PC350	15 ~ 18	18 ~ 21
PC130	11 ~ 14	14 ~ 17	PC400, PC450	16 ~ 19	19 ~ 22
PC160	13 ~ 16	16 ~ 19	PC600	17 ~ 20	20 ~ 23
PW160, PW180	13 ~ 16	16 ~ 19	PC750, PC800, PC850	18 ~ 21	21 ~ 24
PC180	13 ~ 16	16 ~ 19	PC1250	22 ~ 25	25 ~ 28
PC200, PC210	13 ~ 16	16 ~ 19	PC2000	24 ~ 27	27 ~ 30
PW200, 220	14 ~ 17	17 ~ 20			
PC220, PC230, PC240	14 ~ 17	17 ~ 20			

Table 12 Standard cycle time for loading shovel

Model	sec
PC400	16 ~ 20
PC600, PC750, PC800	18 ~ 22
PC1250	20 ~ 24
PC2000	27 ~ 31

Table 13 Conversion factor for excavator

Digging condition $\left(\frac{\text{Digging depth}}{\text{Specified max. digging depth}}\right)$	Dumping condition: Easy (Dump onto spoil pile)	Normal (Large dump target)	Rather difficult (Small dump target)	Difficult (Small dump target requiring maximum dumping reach)
Below 40%	0.7	0.9	1.1	1.4
40 ~ 75%	0.8	1	1.3	1.6
Over 75%	0.9	1.1	1.5	1.8

3. Job efficiency (E)

The following table gives typical job efficiency as a rough guide. To obtain the actual production figure, determine the efficiency in accordance with actual operating conditions.

Operating conditions	Job efficiency
Good	0.83
Average	0.75
Rather poor	0.67
Poor	0.58

(MINING APPLICATION)

The production for Mining Shovels shuld be calculated on loaded trucks per hour

Hourly production = loaded truck per hour x truck capacity x time utilisation

Qh = Tn x Tq x E

Theoretical loaded trucks per hour = 3600 sec/(Loading time per truck + spotting time per truck)

Tn = 3600/(tT + tsp)

Loading time per truck = (truck size/bucket capacity) rounded x cycle time

tT = (Tq/(Bc x K x loose density)) rounded x tc

Gh = hourly production (ton/hr; US ton/hr)
Tn = number of loaded trucks per hour
Tq = truck capacity (ton; US ton)
E = time utilisation per hour (%)

tT = truck loading time (sec)
tsp = truck spotting time (sec)

Bc = bucket capacity (m^3; cu.yd)
K = bucket fill factor (%)
tc = cycle time (sec)

Yearly production = (hours per year - service hours) x availability x mine efficiency

QY = Qh x (hy - hs) x Sa x M

QY = yearly production
hy = theoretical hours per year (hr)
hs = service hour per year (hr)
Sa = mining shovel availability (%)
M = mine efficiency (%)

1. Cycle time (tc)

The following tables give a rough guide line for estimating a production.

Attention:

1) Cycle times are average figures and for diggable material only
2) With skilled operator only
3) Every 10 degrees more swing will increase the cycle time by 1 second
4) Cycle times for standard attachments only
5) Following cycle times are without commitment, due to different job side conditions

(1) Backhoe

Model	Digging conditions			Backhoe application
	Easy	Average	Severe	
PC3000	23 ~ 25	26 ~ 28	29 ~ 31	• Truck on lower level • Average swing 45°
PC4000	23 ~ 26	27 ~ 29	30 ~ 32	
PC5500	24 ~ 27	28 ~ 30	31 ~ 33	
PC8000	25 ~ 28	29 ~ 31	32 ~ 34	

Model	Digging conditions			Backhoe application
	Easy	Average	Severe	
PC3000	32 ~ 35	36 ~ 38	39 ~ 41	• Truck on upper level • Average swing 120° • Optimized working depth 4-5 m (13'1"–16'5")
PC4000	33 ~ 36	37 ~ 39	40 ~ 42	
PC5500	34 ~ 37	38 ~ 40	41 ~ 43	
PC8000	35 ~ 38	39 ~ 41	42 ~ 44	

Model	Digging conditions			Backhoe application
	Easy	Average	Severe	
PC3000	26 ~ 29	30 ~ 32	33 ~ 35	• Split bench application • Average swing 90°–120°
PC4000	27 ~ 30	31 ~ 33	34 ~ 36	
PC5500	28 ~ 31	32 ~ 34	35 ~ 37	
PC8000	29 ~ 32	33 ~ 35	36 ~ 38	

(2) Front shovel

Model	Digging conditions			Front shovel application
	Easy	Average	Severe	
PC3000	24 ~ 26	27 ~ 29	30 ~ 32	• Truck on same level • Average swing 60°
PC4000	24 ~ 27	28 ~ 30	31 ~ 33	
PC5500	25 ~ 28	29 ~ 31	32 ~ 34	
PC8000	26 ~ 29	30 ~ 32	33 ~ 35	

2. Time utilisation per hour (E)

The following table gives typical time utilisation as a rough guide. To obtain the actual production figure, determine the value in accordance with actual operating conditions.

Operating conditions	Time utilisation
Good	0.83
Average	0.75
Rather poor	0.67
Poor	0.58

3. Bucket fill factor (K)

The bucket fill factor varies according to the nature of material.
A suitable factor can be selected from the table, taking into consideration the applicable excavating conditions.

Bucket fill factor (Backhoe)

PC2000 ~ PC8000	Excavating Conditions	Bucket fill factor
Easy	Excavating natural ground of clayey soil, clay, or soft soil	**1.0**
Average	Excavating natural ground of soil such as sandy soil and dry soil	**0.95**
Severe	Excavating natural ground of sandy soil with gravel Loading blasted rock	**0.9**

Bucket fill factor (Front shovel)

PC2000 ~ PC8000	Excavating Conditions	Bucket fill factor
Easy	Loading clayey soil, clay, or soft soil	**1.0**
Average	Loading loose soil with small diameter gravel	**0.95**
Severe	Loading well blasted rock Loading poorly blasted rock	**0.9**

DUMP TRUCKS

When carrying out operations using a suitable number of dump trucks of suitable capacity to match the loader, the operating efficiency is calculated in the following order:

1. Estimating the cycle time

The cycle time of a dump truck consists of the following factors.

(1) Time required for loader to fill dump truck
(2) Hauling time
(3) Time required for unloading (dumping) plus time expended for standby until unloading is started.
(4) Time required for returning
(5) Time required for dump truck to be positioned for loading and for the loader to start loading

Accordingly, the cycle time = (1) + (2) + (3) + (4) + (5)

The cycle time is calculated as follows:

Cycle time of dump truck (Cmt)

$$Cmt = \underset{(1)}{n \times Cms} + \underset{(2)}{\frac{D}{V_1}} + \underset{(3)}{t_1} + \underset{(4)}{\frac{D}{V_2}} + \underset{(5)}{t_2}$$

(1) : Loading time
(2) : Hauling time
(3) : Dumping time
(4) : Returning time
(5) : Spot and delay time

Where, n: Number of cycles required for loader to fill dump truck
$n=C_1/(q_1 \times K)$
C_1 : Rated capacity of dump truck (m^3, yd^3)
q_1 : Bucket capacity of loader (m^3, yd^3)
K : Bucket fill factor of loader
Cms: Cycle time of loader (min)
D: Hauling distance of dump truck (m, yd)
V_1: Average speed of loaded truck (m/min, yd/min)
V_2: Average speed of empty truck (m/min, yd/min)
t_1: Time required for dumping + time required for standby until dumping is started (min)
t_2: Time required for truck to be positioned and for loader to start loading (min)

1) Loading time

The time required for a loader to load a dump truck is obtained by the following calculation.

Loading time = Cycle time (Cms) × No. of cycles to fill dump truck (n)

a) Cycle time of loader (Cms)

The cycle time of a loader is dependent on the type of loader (excavator, crawler type loader, wheel loader, etc.)

For the cycle time of loaders, refer to the section pertaining to the estimation of the production of loaders.

b) Number of cycles required for loader to fill dump truck full (n)

The payload of a dump truck depends on its capacity or weight.

Where the payload is determined by the capacity, $n = \dfrac{\text{Rated capacity (m}^3\text{, yd}^3\text{) of dump truck}}{\text{Bucket capacity (m}^3\text{, yd}^3\text{)} \times \text{bucket fill factor}}$

Where the payload is determined by the weight, $n = \dfrac{\text{Rated capacity (m}^3\text{, yd}^3\text{) of dump truck}}{\text{Bucket capacity (m}^3\text{, yd}^3\text{)} \times \text{bucket fill factor} \times \text{specific weight}}$

* The bucket capacity and the body capacity, as a general rule, refer to heaped capacity but may be used to refer to struck capacity depending on the nature of materials to be handled.

* The bucket fill factor is determined by the nature of soil to be excavated or loaded. In case of dozer shovels or wheel loaders, a suitable factor can be selected from among those given in Table 3, 9, 10 according to the applicable loading condition.

2) Material hauling time and returning time

The time taken to haul a load and return empty, can be calculated by dividing the haul road into sections according to the rolling resistance and grade resistance, as follows.

a) Rolling resistance and grade resistance

As described above, the haul road is divided into several sections according to the rolling resistance and grade resistance. All of these rolling resistance and grade resistance values are summed up, resulting in the totals for each resistance.

The rolling resistance for the haul road conditions can be selected by referring to Table 14. The grade resistance can be obtained by averaging the gradients in all sections, which is converted (from degrees to percent). Table 15 indicates the grade resistance values (%) converted from the angles of gradients.

Table 14 Rolling resistance

Haul road conditions	Rolling resistance
Well-maintained road, surface is flat and firm, properly wetted, and does not sink under weight of vehicle	2%
Same road conditions as above, but surface sinks slightly under weight of vehicle	3.5%
Poorly maintained, not wetted, sinks under weight of vehicle	5.0%
Badly maintained, road base not compacted or stabilized, forms ruts easily	8.0%
Loose sand or gravel road	10.0%
Not maintained at all, soft, muddy, deeply rutted	15 to 20%

Table 15 Grade resistance (%) converted from angle (°) of gradient

Angle	% (sin α)
1	1.8
2	3.5
3	5.2
4	7.0
5	8.7
6	10.5
7	12.2
8	13.9
9	15.6

Angle	% (sin α)
11	19.0
12	20.8
13	22.5
14	24.2
15	25.9
16	27.6
17	29.2
18	30.9
19	32.6

Angle	% (sin α)
21	35.8
22	37.5
23	39.1
24	40.2
25	42.3
26	43.8
27	45.4
28	47.0
29	48.5

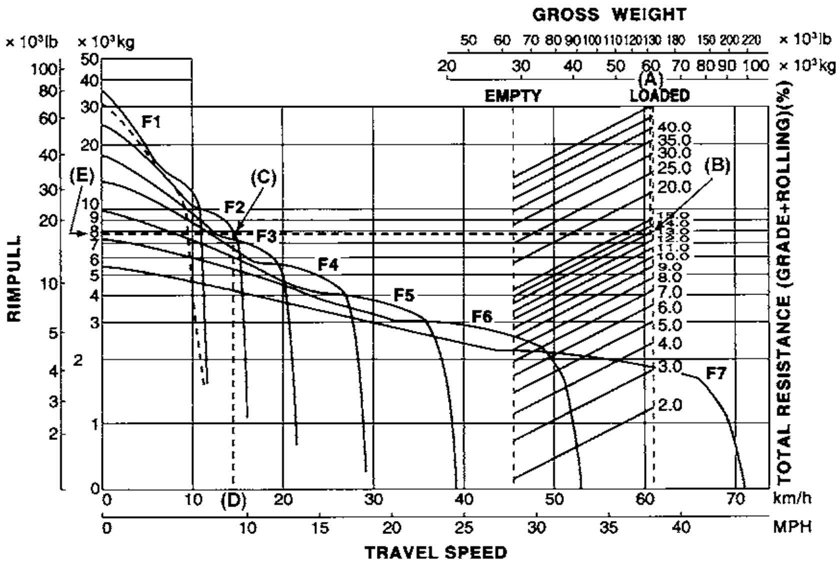
b) Selection of the travel speed

The speed range suited to the resistance, and the maximum speed, can be obtained by using the Travel Performance Curve appears in the spec sheet.

To use, first draw a vertical line according to the vehicle's weight (A) and mark the point (B) corresponding to total resistance (the sum of rolling resistance and grade resistance).

Next, draw a horizontal line from (B), then mark (C) where the line intersects the rimpull curve and read (E) for the rimpull. For travel speed (D), draw a vertical line downward from (C). For instance, when traveling a 8% gradient and encountering a 5 % rolling resistance, a vehicle with a maximum payload should have a rimpull of 8 tons (8.8 ton) and travel at a speed of 15.0 km/h (9.3 MPH) in forward 2nd gear.

Fig. 1 KOMATSU HD325 Dump Truck Travel Performance Curve



The maximum speed thus obtained is a theoretical value, and in order to convert this maximum speed to a practicable average speed, the speed should be multiplied by a speed factor. An applicable speed factor can be selected from the following table.

How to select a speed factor

If a truck is to start off downhill, gear shifting to a desired speed can be accomplished in a short time. In such a case, a rather higher value should be used in each range of factors. On the other hand, if a truck is to start off on a level road or uphill, it will take a comparatively long time for gear-shifting to a desired speed to be accomplished and thus, the lower factor value should be selected in an applicable range of factors.

Table 16 Speed factors

Distance of each section of haul road, m	When making a standing start	When running into each section
0 - 100	0.25 - 0.50	0.50 - 0.70
100 - 250	0.35 - 0.60	0.60 - 0.75
250 - 500	0.50 - 0.65	0.70 - 0.80
500 - 750	0.60 - 0.70	0.75 - 0.80
750 - 1000	0.65 - 0.75	0.80 - 0.85
1000 -	0.70 - 0.85	0.80 - 0.90

Thus, the average speed can be obtained in the following manner:

The average speed =
Maximum vehicle speed obtained from the travel performance curve × (Speed factor)

The above average speed is applicable in ordinary driving conditions. If there is any factor retarding the vehicle speed, an applicable factor should be used.

The following can be cited as factors retarding a vehicle speed.

- Vehicles passing each other on a narrow road
- Sharp curve or many curves in the road
- Points giving poor visibility
- Narrow bridges or at railway crossings, intersections of roads
- Extreme differences in rolling resistance
- Pot-holes on the road
- Un-experienced or unskilled operators

These factors should be eliminated wherever possible.

c) Hauling time

If the hauling distance in each section is divided by the average speed given in the preceding paragraph, the hauling time in each section will be obtained. If all of these times (for hauling and returning) are added together, they will give the total hauling and returning time.

Hauling time and returning time in each section

$$= \frac{\textbf{Length of section (m)}}{\textbf{Average speed (m/min.)}}$$

d) Vehicle speed limitation for a downhill run

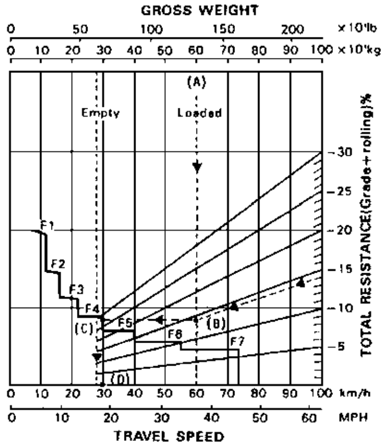
Calculation of a vehicle speed as described in Paragraphs a) to c) is effected with the total resistance in 0 or in a plus value. If the total resistance is a minus value, the vehicle speed will ordinarily be limited by the retarder function with a given distance.

In the case of the HD325 dump truck, the maximum speed at which the truck can safely go down a hill can be obtained in the brake performance curve in Fig. 2. (Grade distance continuous).

For example, assume the total resistance is –14% (gradient resistance is –16% plus rolling resistance +2%) on the "continuous grade" graph. First, draw a vertical line from the total vehicle weight(A) so that it crosses the slanted line of 14% total resistance(B). From(B), draw a horizontal line to the left and it will cross the stair curve at (C).

Finally, draw a vertical line from(C) and read(D) the maximum speed for driving safely down the slope. In this case, a vehicle with a 32-ton payload should travel at approximately 30 km/h (18.6 MPH) in forward 4th gear.

Fig. 2 HD325 Brake Performance (Grade distance continuous)



3) Dumping time

This is the period from the time when the dump truck enters the dumping area, to the time when the dump truck starts its return journey after completing the dumping operation. The length of the dumping time depends on the operating conditions, but average dumping times for favorable average and unfavorable conditions are given by the following table.

However, particularly adverse conditions giving rise to extremely long dumping times are excluded.

Operating conditions	t_1, min.
Favorable	0.5 to 0.7
Average	1.0 to 1.3
Unfavorable	1.5 to 2.0

4) Time required for the truck to be positioned and for the loader to begin loading.

The time taken for the truck to be positioned and for the loader to begin loading also depends on the operating conditions. As a general rule, a suitable time can be selected from the table at right.

As has so far been described, the cycle time of a dump truck can be estimated by using the values for factors obtained according to paragraph 1) to 4).

Operating conditions	t_2, (min.)
Favorable	0.1 to 0.2
Average	0.25 to 0.35
Unfavorable	0.4 to 0.5

2. Estimating the number of dump trucks required (M)

The quantity of dump trucks required for use in combination with a loader working at its maximum operating efficiency can be estimated by the following formula:

$$M = \frac{\text{Cycle time of a dump truck}}{\text{Loading time}} = \frac{Cmt}{n \times Cms}$$

Where, n : Number of cycles required for a loader to fill a dump truck
Cms : Cycle time of loader (min)
Cmt : Cycle time of dump truck (min)

3. Estimating the productivity of dump trucks

The total hourly production P of several dump trucks where they are doing the same job simultaneously is estimated by the following formula:

$$P = C \times \frac{60}{Cmt} \times E_t \times M$$

Where, P : Hourly production (m^3/h;yd^3/hr)
E_t : Job efficiency of dump truck
M : Q'ty of dump trucks in operation
C : Production per cycle $C = n \times q_1 \times K$
Where, n : Number of cycles required for loader to fill dump truck
q_1 : Bucket capacity of loader (m^3, yd^3)
K : Bucket fill factor of loader
Cmt : Cycle time of dump truck

Table 16 gives typical job efficiency as a rough guide.

To obtain the actual production figure, determine the efficiency in accordance with actual operating conditions.

Table 16 Job efficiency of dump truck (Et)

Operating conditions	Job efficiency
Good	0.83
Average	0.80
Rather poor	0.75
Poor	0.70

4. Combined use of dump trucks and loaders

When dump trucks and loaders are used in combination, it is most desirable that the operating capacity of the dump trucks be equal to that to the loaders. That is, conditions satisfying the following equation are most desirable. Consequently, if the value of the left equation is larger, the group of dump trucks has a surplus capacity. On the other hand, if the value of the right equation is larger, the group of loaders has a surplus capacity.

$$C \times \frac{60}{Cmt} \times E_t \times M \geqq q_1 \times K \times \frac{60}{Cms} \times Es$$

Where, Cms : Cycle time of a loader (min)
q_1 : Bucket capacity (heaped (m^3; yd^3))
Es : Job efficiency of loader
K : Bucket fill factor

The left equation has already been described. The right equation has the following meaning.

EXAMPLE

- **A HD325, working in combination with a WA600, is hauling excavated material to a spoil-bank 500 meters away.**
  What is the hauling capacity of the HD325?

Working conditions for dump truck:

Haul distance: flat road: 450 m
slope: 50 m
gradient of slope: 10%

Haul road condition:
Road with sunken surface, not wetted, poorly maintained.

Type of soil:
Sandy clay (loose density 1.6 tons/ m^3)

Job efficiency:
0.83 (good operating conditions)

Speed limits:
For safety purposes, the following maximum speeds should not be exceeded.

		Speed
Flat	Loaded	40 km/h
	Unloaded	60 km/h
Uphill	Loaded	20 km/h
	Unloaded	40 km/h
Downhill	Loaded	20 km/h
	Unloaded	40 km/h

Wheel Loader: Bucket capacity : 5.4m^3 (7.1cu.yd)
Cycle time : 0.65 min
Bucket fill factor : 0.9
Job efficiency : 0.83

Answer

(a) Cycle time (Cmt)

(i) Loading time

Cycle time of loader Cms = 0.65 min
Number of cycles required for loader to fill dump truck

$$n = \frac{\text{Rated capacity of dump truck}}{\text{Bucket capacity} \times \text{bucket fill factor} \times \text{loose density}} = \frac{\text{32 tons (max. payload)}}{5.4\ m^3 \times 0.9 \times 1.6} = 4.12$$

n is taken to be 4.

Loading time = n × Cms = 4 × 0.65 = 2.60 min.

(ii) Hauling time and returning time

The hauling distance is divided up and the time taken to cover each section should be calculated.

Hauling:			Returning:		
	1 Flat	330 m		4 Flat	120 m
	2 Uphill	50 m		5 Downhill	50 m
	3 Flat	120 m		6 Flat	330 m

Net weight of dump truck (unloaded): 27,200 kg (figure in specifications)

Loaded weight :

Weight when loaded = n × bucket capacity × bucket fill factor × loose specific gravity × 1,000
= 4 × 5.4 m^3 × 0.9 × 1.6 × 1,000 = 31,104 kg

Weight of loaded dump truck= 27,200 kg + 31,104 kg = 58,304 kg

Using the Travel Performance Curve and Brake Performance Curve, the maximum speed for each section can be calculated.
The values for HD325 can be calculated from PERFORMANCE CURVE on the section 7A.

The result is shown in the table below and the table of Hauling time and Returning time is 3.00 min.

Calculation of Hauling time and Returning time

		Dis-tance	Grade Resis-tance	Rolling Resis-tance	Total Resis-tance	Speed Range	Max. Travel Speed	Speed Factor	Ave. Speed	Time Taken
Hauling (Loaded)	Flat	330	0	5%	5%	F5	36 km/h (600 m/min)	0.50	300.0 m/min	1.10 min
	Uphill	50	10 %	5%	15%	F2	11 km/h (183 m/min)	0.60	109.8 m/min	0.46
	Flat	120	0	5%	5%	F5	36 km/h (600 m/min)	0.60	300.0 m/min	0.40
Returning (Unloaded)	Flat	120	0	5%	5%	F6	53 km/h (883 m/min)	0.35	309.1 m/min	0.39
	Down-hill	50	-10 %	5%	-5%	F6	*40 km/h (667 m/min)	0.70	466.9 m/min	0.11
	Flat	330	0	5%	5%	F6	53 km/h (883 m/min)	0.70	618.1 m/min	0.54
									Total	3.00 min

*: In the Brake Performance Curve (Fig. 2), the figure for total resistance is given as –5%. This means that when driving unloaded and using the speed range F6 as shown in the diagram, it is enough to press the accelerator pedal and keep within the speed limit.

(iii) Dumping time and standby time

t_1 = 1.15 min. (average)

(iv) Time required for the dump truck to be positioned for loading, and for the loader to start loading

t_2 = 0.3 min. (average)

(v) Cycle time

Cmt = 2.60 + 3.00 + 1.15 + 0.3 = 7.05 min.

(b) Estimating the production of dump truck

$$P = C \times \frac{60}{Cmt} \times Et = 19.44 \times \frac{60}{7.05} \times 0.83 = 137.3\ m^3/h$$

$C = n \times$ bucket capacity $\times$ bucket fill factor $= 4 \times 5.4 \times 0.9 = 19.44\ m^3$

MOTOR GRADERS

The motor grader is used for many purposes such as maintaining roads, final finishing for earthmoving projects, trenching and bank cutting.

Therefore there are many methods of expressing its operating capacity.

1. Calculating the hourly operating area (m^2/h)

$$Q_A = V \times (L_e - L_o) \times 1000 \times E$$

Where Q_A **: Hourly operating area (m^2/hr)** V **: Working speed (km/hr)**
L_e **: Effective blade length (m)** L_o **: Width of overlap (m)**
E **: Job efficiency**

NOTE: Graders usually operate on long stretches, so the time required for gear shifting or turning can be ignored.

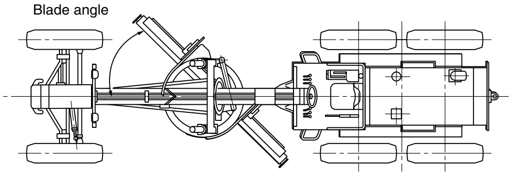
1) Working speed (V)

Road repair : 2 to 6 km/h
Bank finishing: 1.6 to 2.6km/h
Field grading : 1.6 to 4 km/h
Trenching : 1.6 to 4 km/h
Snow-removal: 7 to 25 km/h
Leveling : 2 to 8 km/h

2) Effective blade length (Le), width of overlap (Lo)

Since the blade is normally angled when cutting or grading the surface, the effective blade length depends on the angle.

The width of overlap is usually 0.3 m. Following table gives the values to be used when applying the formula.



Blade length (m)	Effective blade length (m)	
	Blade angle 60°	Blade angle 45°
2.2	1.9	1.6
2.5	2.2	1.8
2.8	2.4	2.0
3.05	2.6	2.2
3.1	2.7	2.2
3.4	2.9	2.4
3.7	3.2	2.6
4.0	3.5	2.8
4.3	3.7	3.0
4.9	4.2	3.5

3) Job efficiency (E)

The following table gives typical job efficiency as a rough guide. To obtain the actual production figure, determine the efficiency in accordance with actual operating conditions.

Operating conditions	Job efficiency
Road repair, leveling	0.8
Snow-removal (V-type plow)	0.7
Spreading, grading	0.6
Trenching, snow-removal	0.5

2. When calculating the time required to finish a specific area.

$$T = \frac{N \times D}{V \times E}$$

Where **T = Working time (h)** **N = Number of trips**
D = Working distance (km) **V = Working speed (km/hr)**
E = Job efficiency

Number of trips (N)
When a grader is operating in a job site, and leveling parallel strips, the number of trips can be calculated by using the following formula:

$$N = \frac{W}{Le - Lo} \times n$$

Where W : Total width to be leveled (m) Le : Effective blade length (m)
Lo : Width of overlap (m)
n : Number of grading required to finish the surface to the required flatness.

SOIL COMPACTORS

There are two ways of expressing the productivity of compactors: by the volume of soil compacted, and by the area compacted.

1. Expressing productivity by the volume of soil compacted.
When calculating the productivity by the volume of soil compacted, the following formula is used.

$$Q = \frac{W \times V \times H \times 1000 \times E}{N}$$

Where
Q = Hourly production (m^3/hr)(volume of soil compacted)
V = Operating speed (km/hr)
W = Effective compaction width per pass (m)
H = Compacted thickness for one layer (m)
N = Number of compaction (number of passes by compactor)
E = Job efficiency

1) Operating speed (V)
As a general rule the following values are used.

Road roller	about 2.0 km/hr
Tire roller	about 2.5 km/hr
Vibration roller	about 1.5 km/hr
Soil compactor	4 - 10 km/hr
Tamper	about 1.0 km/hr

2) Effective compaction width (W)

Type of Equipment	W
Macadam roller	Driving wheel width - 0.2 m
Tandem roller	Driving wheel width - 0.2 m
Soil compactor	(Driving wheel width × 2) - 0.2 m
Tire roller	Outside-to-outside distance of most outside tires - 0.3 m
Large vibratory roller	Roller width - 0.2 m
Small vibratory roller	Roller width - 0.1 m
Bulldozer	(Width of track shoe × 2) - 0.3 m

3) Compacted thickness for one layer (H)
Compacted thickness is determined from compaction specifications or from the results of tests, but as a general rule, it is 0.2 ~ 0.5 m in loosened soil.

Number of trips (N)

When a grader is operating in a job site, and leveling parallel strips, the number of trips can be calculated by using the following formula:

$$N = \frac{W}{Le - Lo} \times n$$

Where W : Total width to be leveled (m) Le : Effective blade length (m)
Lo : Width of overlap (m)
n : Number of grading required to finish the surface to the required flatness.

SECTION **14B**

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 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 terrain.

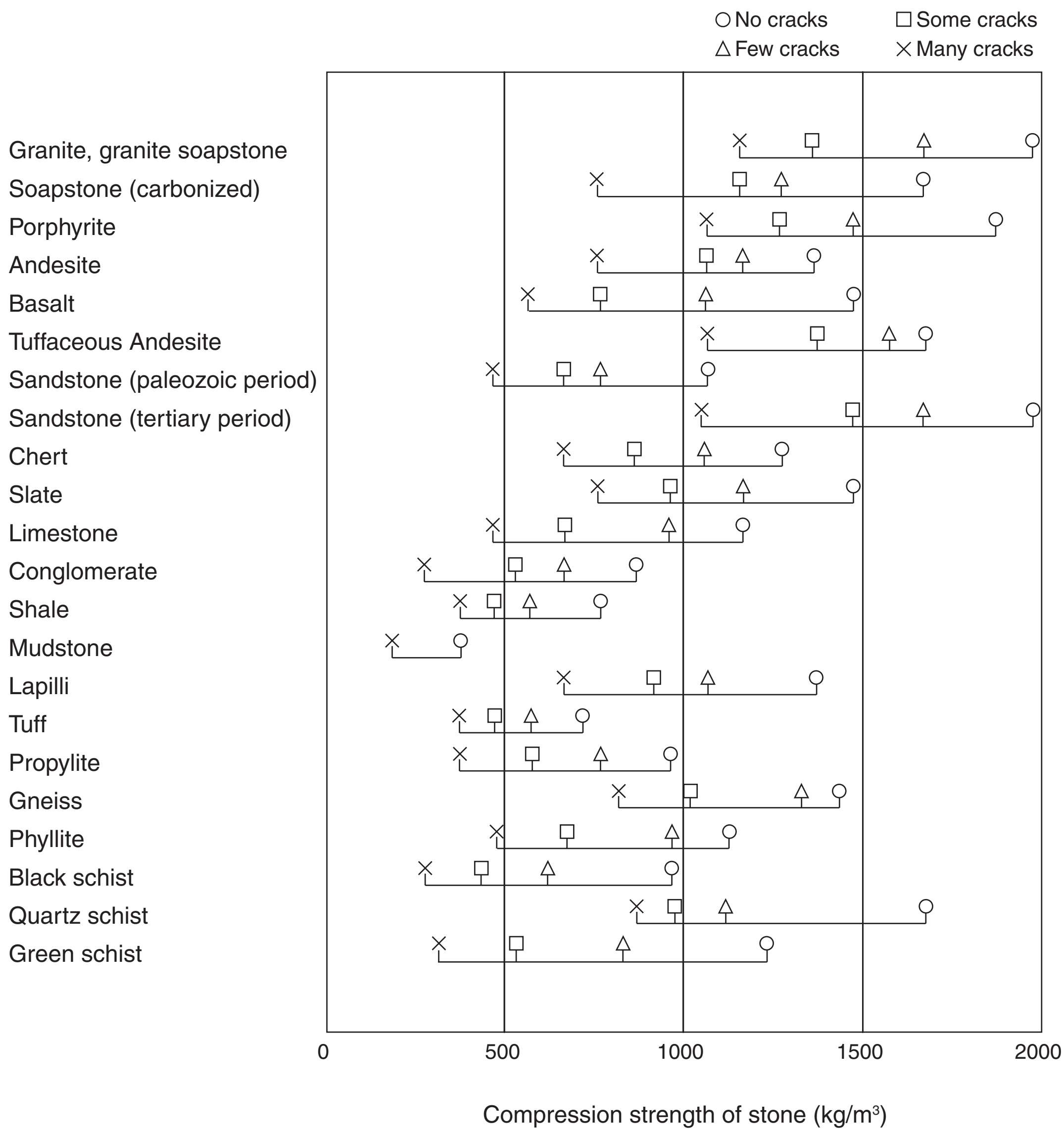
* Data (figures) to be given hereinafter vary largely depending on various operating and environmental conditions. Consequently, before starting the earth work, tests should be conducted to obtain correct data for operations.

Some knowledge of the weight data per unit volume of materials of 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.

WEIGHT DATA OF MATERIALS

Material		Specific Gravity (ton/m^3)	
		Bank	Crushed (Loose)
Basalt		2.95	1.7
Bauxite		1.9	1.42
Caliche		2.26	1.25
Carnotite, uranium ore		2.2	1.63
Cinders		0.86	056
Clay		1.8	1.45
Clay & gravel		2.0	1.45
Coal	**Anthracite**	1.3	1.0
	Bituminous	0.59 ~ 0.89	0.53 ~ 0.65
Decomposed Rock -			
75% Rock, 25% Earth		2.0	1.75
50% Rock, 50% Earth		2.1	1.75
25% Rock, 75% Earth		2.2	1.65
Earth -			
Dry		1.8	1.4
Wet		2.0	1.6
Loam		1.54	1.25
Granite		2.8	1.6
Gravel		2.17	1.93
Gypsum		3.17	1.81
Hematite, iron ore		3.5	2.0
Limestone		2.8	1.6
Magnetite, iron ore		5.05	2.9
Peat	**Dry**	0.60 ~ 0.70	0.40 ~ 0.50
	Wet	1.80 ~ 2.00	1.10 ~ 1.20
Pyrite, iron ore		3.03	2.85
Sand -			
Dry		1.6	1.42
Dump		1.9	1.69
Wet		2.08	1.84
Sand & clay	**Loose**	2.02	1.6
	Compacted	—	2.4
Sand & gravel	**Dry**	1.93	1.72
	Wet	2.23	2.02
Sandstone		2.7	1.55
Slag		2.94	1.75
Snow	**Dry**	—	0.13
	Wet	—	0.52
Stone		2.67	1.6
Taconite		2.36 ~ 2.7	1.63 ~ 1.9
Top soil		1.37	0.95
Trap rock		2.50 ~ 2.70	1.60 ~ 1.80

ROCK TYPES AND COMPRESSION STRENGTHS

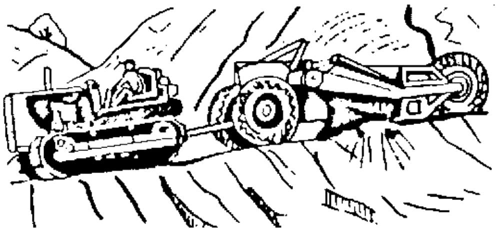


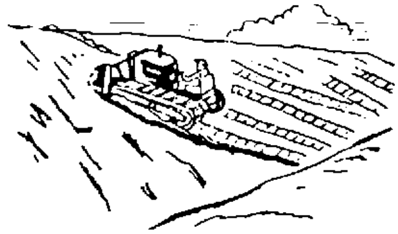
HAULING PERFORMANCE OF CONSTRUCTION MACHINES

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 (traction 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 traction 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
F2	3.5	19700	—
F3	4.9	14100	—
F4	6.4	10780	—
F5	8.9	7670	—
F6	12.9	5350	—

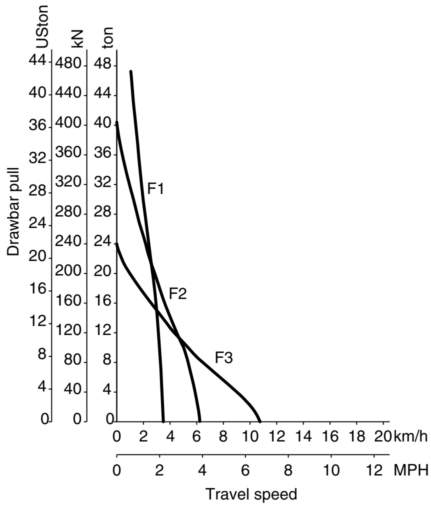
The rated drawbar pull is such a traction force that can be developed at the rated engine power and the rated revolutions (rpm). The rated drawbar pull is normally estimated by taking into account the travelling resistance (which will be explained later) and the mechanical loss of power in its line from the engine to the sprockets.

The maximum drawbar pull is the maximum traction 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 at right 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 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 traction force is increased with the added load.
(2) Install chain to 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 traction force is increased by the higher coefficient of traction.

The above facts can also be applied to a crawler tractor. Now, let us look at the coefficient of cohesion and the critical traction 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)

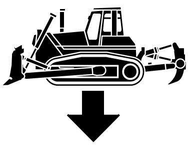
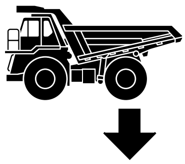
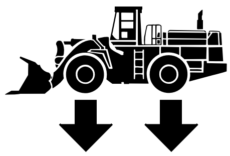
μd : Coefficient of traction

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 machine	4-wheel drive machine
		
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, $Fd = 0.60 \times 26730 = 16040$ 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 $11400 \times 0.60 = 6840$ kg.

The rated drawbar pull indicated in its specifications is 8280 kg at F1 or 5920 kg at F2.

Consequently

at F1: The rated drawbar pull is 8280kg, but the tracks will start shoe slip at the drawbar pull beyond 6840kg, making it impossible 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 5920kg. Thus, the drawbar pull can be utilized to the full.

MACHINE CAPABILITIES REQUIRED FOR EARTHMOVING 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 retarding 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.

$$Wr = \mu r \bullet G$$

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.

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 tires 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 terran.

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

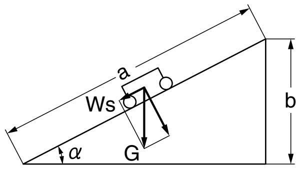
Example (4)	What is the rolling resistance of the D155 tractor to pull the RS24 scraper loaded full. The ground surface is in a dry loose terran.

Solution: The net weight of an RS24 is 18000 kg
The maximum payload is 34080 kg
The gross weight is 52080 kg
Thus, the rolling resistance = 0.045 × 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.

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



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

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

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 × 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	Haul 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 maximum load?

Solution: The gross weight of the RS08 with maximum load is 18870 kg.

The rolling resistance factor is 0.045. Thus, the rolling resistance is 0.045 × 18870 = 850 kg

The weight of the D60-6 tractor is 12550 kg.

The gross weight of the RS08 is 18870 kg.

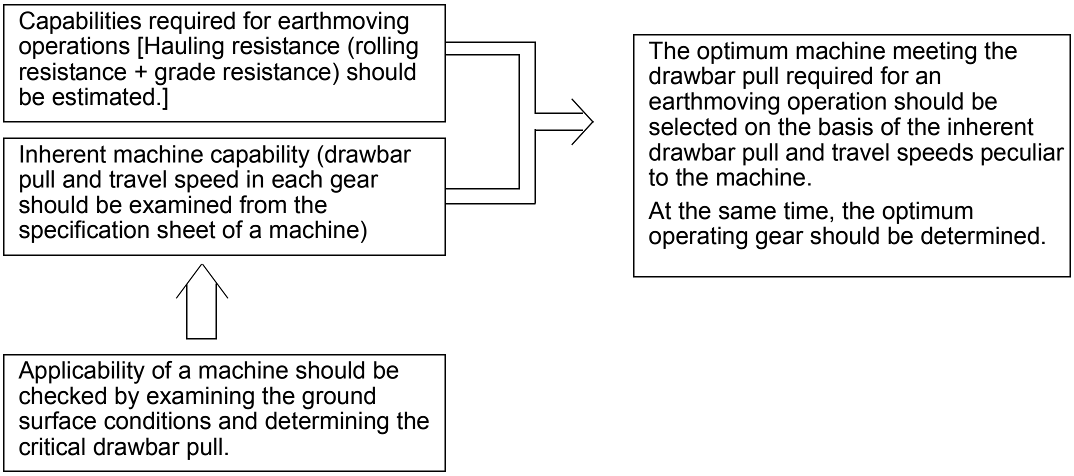
Then, the total weight of both machines is 31420 kg

Consequently, the grade resistance is 0.07 × 31420 = 2200 kg.

Thus, the hauling resistance is 850 + 2200 = 3050 kg.

SUMMARY AND APPLICATION

1. Summary



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 climbable under the same condition?

Solution: <u>**The rolling resistance**</u>

Weight of the wagon (empty): 17000 kg   Payload: 50000 kg

Total weight: 67000 kg   Coefficient of rolling resistance: 0.045

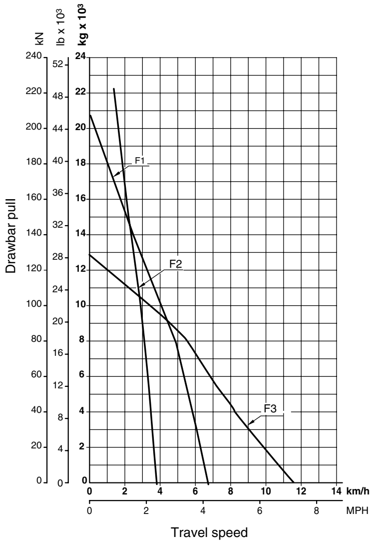
Consequently the rolling resistance against the wagon is 67000 × 0.045 = 3015 kg

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. 9.0 km/h at F3 or

approx. 6.0 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 × 0.60 = 7650 kg

Degree of a climbable hill (gradeability)

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

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

Consequently,

$$\textbf{Gradeability} \left(\frac{\textbf{Critical drawbar pull – rolling resistance}}{\textbf{Grade resistance per angle of grade}} \right) \textbf{will be } \frac{7650 - 3015}{1435} = 3.2 \textbf{ (degree)}$$

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 instance where a tractor pulls a scraper, it can be judged whether the tractor can be used for this purpose, but it can 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 reference 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 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 are cases where a construction machine cannot be operated because of the type and conditions of soil. The degree of the traveling capability of a construction machine is called the traffic-ability.

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

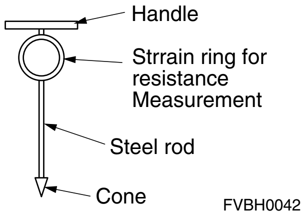
The larger the cone index number becomes, the higher the traffic-ability of the machine will become. In other words, on the soil larger in cone index No., a construction machine will be able to travel easier.

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/cm^2)
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 (D20 ~ D31)	0.3 ~ 0.6
5 to 7	Medium-size bulldozer (D41~D75S)	0.6 ~ 0.8
7 to 10	Large-size bulldozer (D85 ~ D575) & towed scraper	0.7 ~ 1.5
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.

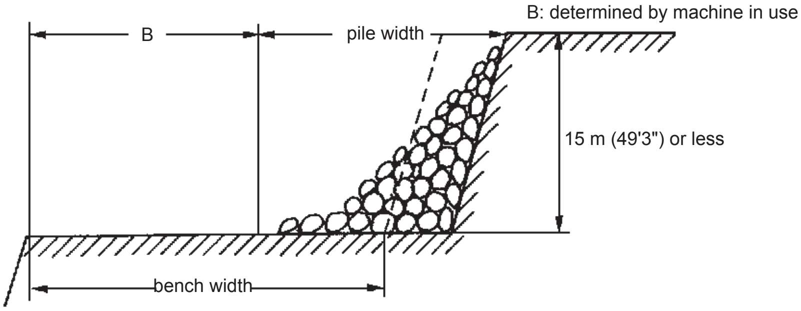


* Cone index numbers (qc)

A cone index number is measured by means of a cone penetro-meter 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 number can be obtained by referring the estimated shearing strength to the conversion table attached to the meter.

1. Blasting and bench width

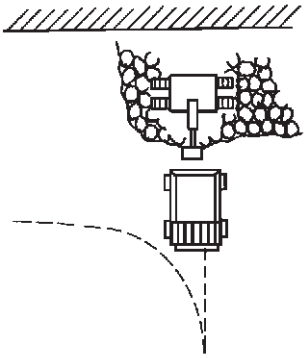
Minimum bench width should be at least twice the cutting face height.



2. Machine and bench width

2.1 Excavator loading to the dump truck

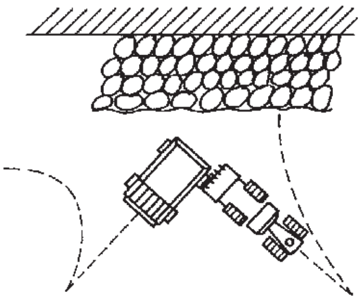
Bench width must be at least three times the dump truck's turning radius.



Model	Min. turning radius m (ft.in)	Bench width m (ft.in)
HD255	7 (23')	21 (68'11")
HD325	7.2 (23'7")	22 (72'2")
HD405	7.2 (23'7")	22 (72'2")
HD465	8.5 (27'11")	27 (88'7")
HD605	8.5 (27'11")	27 (88'7")
HD785	9.9 (32'6")	30 (98'5")
HD1500	12.2 (40')	36 (118'1")
730E	14.0 (45'11")	42 (137'10")
830E	14.2 (46'7")	43 (141'1")
930E	12.36 (40'7")	37 (121'5")

2.2 Wheel loader loading to the dump truck

Bench width must be at least three times the wheeled loader's length.



Model	Wheel loader length m (ft.in)	Bench width m (ft.in)
WA500	9.4 (30'10")	29 (95'2")
WA600	11.0 (36'1")	33 (108'3")
WA700	12.5 (41')	38 (124'8")
WA800	13.7 (44'11")	42 (137'10")
WA900	14.3 (16'11")	42 (137'10")
WA1200	18.2 (59'9")	55 (180'5")

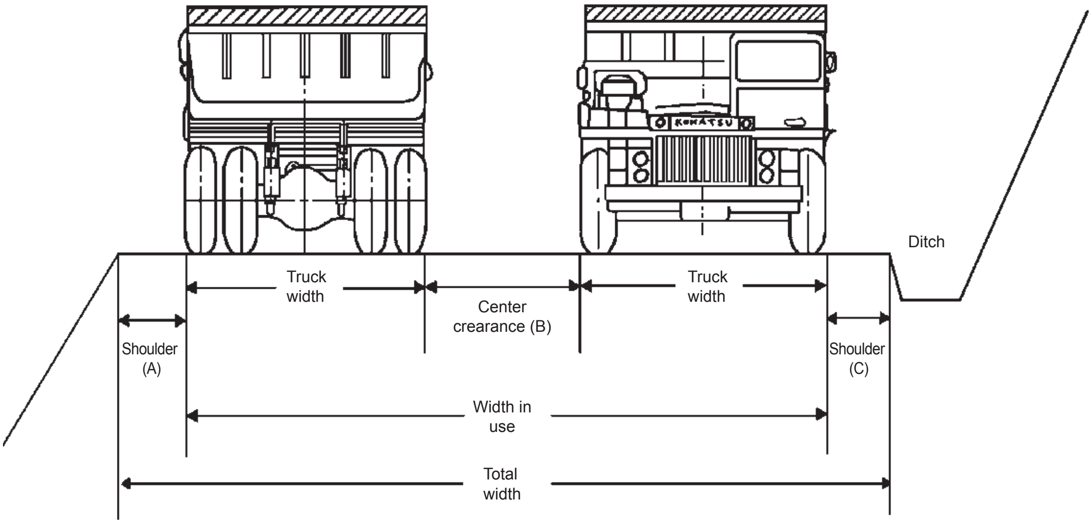
3. Haul road planning

3.1 Dump truck width and haul road size

The width dump truck haul road must have sufficient room to accommodate the model of dump truck planned for use on the site.

In order to accommodate one lane in each direction, with trucks going 30 km/h (18.6 MPH), the haul road must be at least four times the truck width

Dump truck width and haul road size



Model	Speed km/h (MPH)	Center clearance (B) m (ft.in)	Downhill shoulder (A) m (ft.in)	Uphill shoulder (C) m (ft.in)	Total road width m (ft.in)
HD255-5 Truck width 3.2 m (10'6")	20 (12.4) 30 (18.6) 40 (24.9)	2.0 (6'7") 2.5 (8'2") 3.0 (9'10")	2.0 (6'7") 2.0 (6'7") 2.0 (6'7")	1.0 (3'3") 1.5 (4'11") 1.5 (4'11")	11.4 (37'5") 12.4 (40'8") 12.9 (42'4")
HD325-6 Truck width 3.7 m (12'2")	20 (12.4) 30 (18.6) 40 (24.9)	3.0 (9'10") 3.0 (9'10") 3.5 (11'6")	2.0 (6'7") 3.0 (9'10") 3.0 (9'10")	1.5 (4'11") 1.5 (4'11") 2.0 (6'7")	13.8 (45'3") 14.9 (48'11") 15.9 (52'2")
HD405-6 Truck width 3.7 m (12'2")	20 (12.4) 30 (18.6) 40 (24.9)	3.0 (9'10") 3.0 (9'10") 3.5 (11'6")	2.0 (6'7") 3.0 (9'10") 3.0 (9'10")	1.5 (4'11") 1.5 (4'11") 2.0 (6'7")	13.8 (45'3") 14.9 (48'11") 15.9 (52'2")
HD465-7 Truck width 4.2 m (13'9")	20 (12.4) 30 (18.6) 40 (24.9)	3.0 (9'10") 3.5 (11'6") 3.5 (11'6")	3.0 (9'10") 3.0 (9'10") 3.5 (11'6")	1.5 (4'11") 2.0 (6'7") 2.5 (8'2")	15.9 (52'2") 16.9 (55'5") 17.9 (58'9")
HD605-7 Truck width 4.2 m (13'9")	20 (12.4) 30 (18.6) 40 (24.9)	3.0 (9'10") 3.5 (11'6") 3.5 (11'6")	3.0 (9'10") 3.0 (9'10") 3.5 (11'6")	1.5 (4'11") 2.0 (6'7") 2.5 (8'2")	15.9 (52'2") 16.9 (55'5") 17.9 (58'9")
HD785-5 Truck width 5.7 m (18'8")	20 (12.4) 30 (18.6) 40 (24.9)	3.5 (11'6") 4.0 (13'1") 4.5 (14'9")	3.5 (11'6") 4.5 (14'9") 4.5 (14'9")	2.5 (4'11") 2.5 (6'7") 3.0 (8'2")	20.9 (68'7") 22.4 (73'6") 23.4 (76'9")
HD1500 Truck width 6.62 m (21'9")	20 (12.4) 30 (18.6) 40 (24.9)	3.5 (11'6") 4.0 (13'1") 4.5 (14'9")	3.5 (11'6") 4.5 (14'9") 4.5 (14'9")	2.5 (8'2") 2.5 (8'2") 3.0 (9'10")	22.7 (74'6") 24.2 (79'5") 25.2 (82'8")

Model	Speed km/h (MPH)	Center clearance (B) m (ft.in)	Downhill shoulder (A) m (ft.in)	Uphill shoulder (C) m (ft.in)	Total road width m (ft.in)
730E Truck width 7.25 m (23'9")	20 (12.4) 30 (18.6) 40 (24.9)	3.5 (11'6") 4.0 (13'1") 4.5 (14'9")	4.0 (13'1") 5.0 (16'5") 5.0 (16'5")	2.5 (8'2") 2.5 (8'2") 3.0 (9'10")	24.5 (80'5") 26.0 (85'4") 27.0 (88'7")
830E Truck width 7.26 m (23'10")	20 (12.4) 30 (18.6) 40 (24.9)	3.5 (11'6") 4.0 (13'1") 4.5 (14'9")	4.0 (13'1") 5.0 (16'5") 5.0 (16'5")	2.5 (8'2") 2.5 (8'2") 3.0 (9'10")	24.5 (80'5") 26.0 (85'4") 27.0 (88'7")
930E-3 Truck width 8.69 m (20'6")	20 (12.4) 30 (18.6) 40 (24.9)	4.0 (13'1") 4.5 (14'9") 5.0 (16'5")	4.0 (13'1") 5.0 (16'5") 5.0 (16'5")	2.5 (8'2") 2.5 (8'2") 3.0 (9'10")	27.9 (91'6") 29.4 (96'6") 30.4 (99'9")

3.2 Haul road grade

For best fuel efficiency and safety against slippage, etc, the road's grade should ideally be under 10%.