EARTHMOVING PLAN

Yamazaki Construction Co.,Ltd.

CONTENTS

1．Construction Mechanization

2．Framing of Earthmoving Execution Plan

3．Selection of Earthmoving Equipment

3.1 Kinds of Work

3.2 The effect to use popularized or standard type equipments

4．Cost of Earthmoving

5．Estimate Production

5.1 Working Ability of a Equipment

5.2 Volume Change Characteristics of Soils

5.3 Fleet Production

5.4 Productivity of Combination Work by oneself

6．Workability and Soil Condition

6.1 Trafficability

6.2 Excavatability

6.3 Ripperability

6.4 Compactability

7．Hauling Distance

8．Gradeability

9．Operating Control for Equipment

1. Construction Mechanization

Since some form of equipment is used in every operation in present construction work, work and equipment have a very close relationship. The meaning of construction mechanization is condensed into the following.

(1) To realize the works beyond human power
(2) To decrease the cost
(3) To shorten the term
(4) To uniform the quality of structure

As mentioned above, in construction work the advantages of mechanization are great, but on the other hand, mistakes in control would result in big losses. Therefore, it is necessary for site engineer to have knowledge and experience, and to use a method of control suited to the site.

Advantages of mechanization are:
(1) Larger scale operations possible
(2) Reduced work time
(3) Uniformity and improvement
(4) Making larger operating unit
(5) Reduced manpower
(6) Relief from heavy manual or exhausting work
(7) Improved operating safety

But disadvantages of mechanization are:
(1) Large capital needed for obtaining equipments
(2) Increased management work for equipments
(3) Problems with training and keeping operations
(4) Effort needed to keep up efficient control of mechanization

It needs optimum selection and management of equipments to succeed in the construction mechanization.

12m^3-Wheel Loader & 90t-Dump Truck

2. Framing of Earthmoving Execution Plan

In general case, procedure of earthmoving work plan is investigated outline of whole process to complete within the term at first, and finished by adjusting the rough plan according to conditions at several process.

Earthmoving execution plan is carried out by following procedure in general in case of road construction.

① Understanding of specifications and site condition according to design data and surveying of the field.

② Setting up rational distribution of soil by considering cutting area, filling area and quantity, etc.

③ Deciding optimum working lot by considering distribution of soil and relation with other structures and works.
Checking the relation in connection with each major working process.

④ Selecting the work method and the equipment in major working process.
Estimating the approximate cost of work and comparing with the cost of other methods when selecting the work method.

④ Estimating the work period and summing up to them in each process. As next stage, adjusting several periods in order to accept within the term, and finally completing the whole process.

⑤ Adding sub working process and attached working process to major process, and making whole plan.

⑥ Reviewing, correcting or adjusting about the detail of the whole plan and finishing the plan completely.

⑧ Making the schedule chart of work plan to apply the working control.

D11 with Impact ripper (Ripper+ Breaker)

3. Selection of Earthmoving Equipment

Earthmoving are usually many alternatives of construction method.
It has to consider many factors which are soil condition, working area, hauling distance, quantity, construction term, weather, etc. when selecting earthmoving equipment.

3.1 Kinds of Work

Table-1 Kinds of work and equipments

Kinds of Work	Equipments
Clearing	Bulldozer, Rakedozer, Backhoe, Chipper
Excavating	Shovel (Backhoe, Dragline, Clamshell) Bulldozer, Ripper, Rock breaker
Loading	Wheel Loader, Track Loader Loading shovel (Front shovel)
Excavating / Loading	Power shovel (Backhoe, Dragline, Clamshell) BWE(Bucket Wheel Excavator)
Excavating / Hauling	Bulldozer, Scrapedozer, Scraper
Hauling	Dump truck (Rigid, Articulated), Wagon, Conveyer Clowler dump
Spreading / Grading	Bulldozer, Wheel dozer, Motor grader
Compacting.	Tire roller, Steel roller, Vibration roller, Tamping roller, Vibration compactor, Tamper, Bulldozer
Trenching	Trencher, Backhoe
Maintaining macadam road	Motor grader
Slant finishing	Backhoe, Motor grader
Rock Braking	Drill, Breaker, Spliter

Chipper

3.2 The effect to use popularized or standard type equipments

In general, it can consider that the equipment having lager size assures a lower cost of working. However it often happens that use of large size equipment does not always its ability to be fully demonstrated.

Because it requires a higher cost of transporting and disassembles/assemble, to increase the loss due to repairs and suspension, thus it results to be uneconomically.

It can be said concerned with special made equipment in the same reason.

Therefore generally speaking, the popularized or standard type equipment is mostly advantageous from technical and economical viewpoint.

The effect to use popularized or standard type equipment are following.

1) They may be obtained easily and quickly.
2) They can be used economically on more than one project,
3) Repair parts for them may be obtained quickly and economically.
4) When they are no more needed, they can be usually disposed easily and at a favorable price.

Table-2 Popularized or standard type equipments in Japan

Kinds of Equipment	Popularized or standard type	
Bulldozer	Normal	7 ～ 27 (ton)
	Swamp	7 ～ 27 (ton)
Bulldozer with ripper	Normal	27 ～ 103 (ton)
Scrapedozer	Normal	8.0 (m^3)
Tractor-pulled scraper		9, 15, 23 (m^3)
Motor scraper	Single engine	24 (m^3)
	Tandem engine	24 ～ 34 (m^3)
Backhoe(hydraulic type)		0.01 ～ 11 (m^3)
Clamshell	Hyd.	0.3, 0.8 (m^3)
Loader	Track-type	0.4 ～ 3 (m^3)
	Wheel-type	0.4 ～ 12 (m^3)
Dump truck		4 ～ 15 (ton)
	Off-Highway	20 ～ 90 (ton)

Scrapedozer SR280

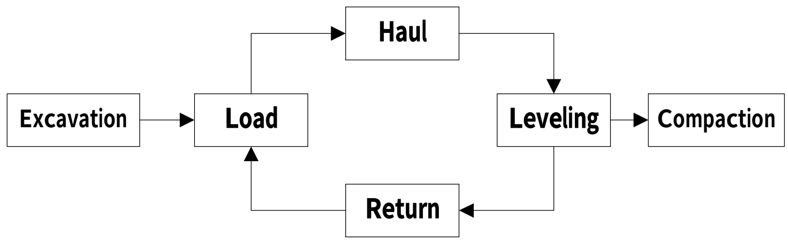


Fig.1 Earthmoving Flow

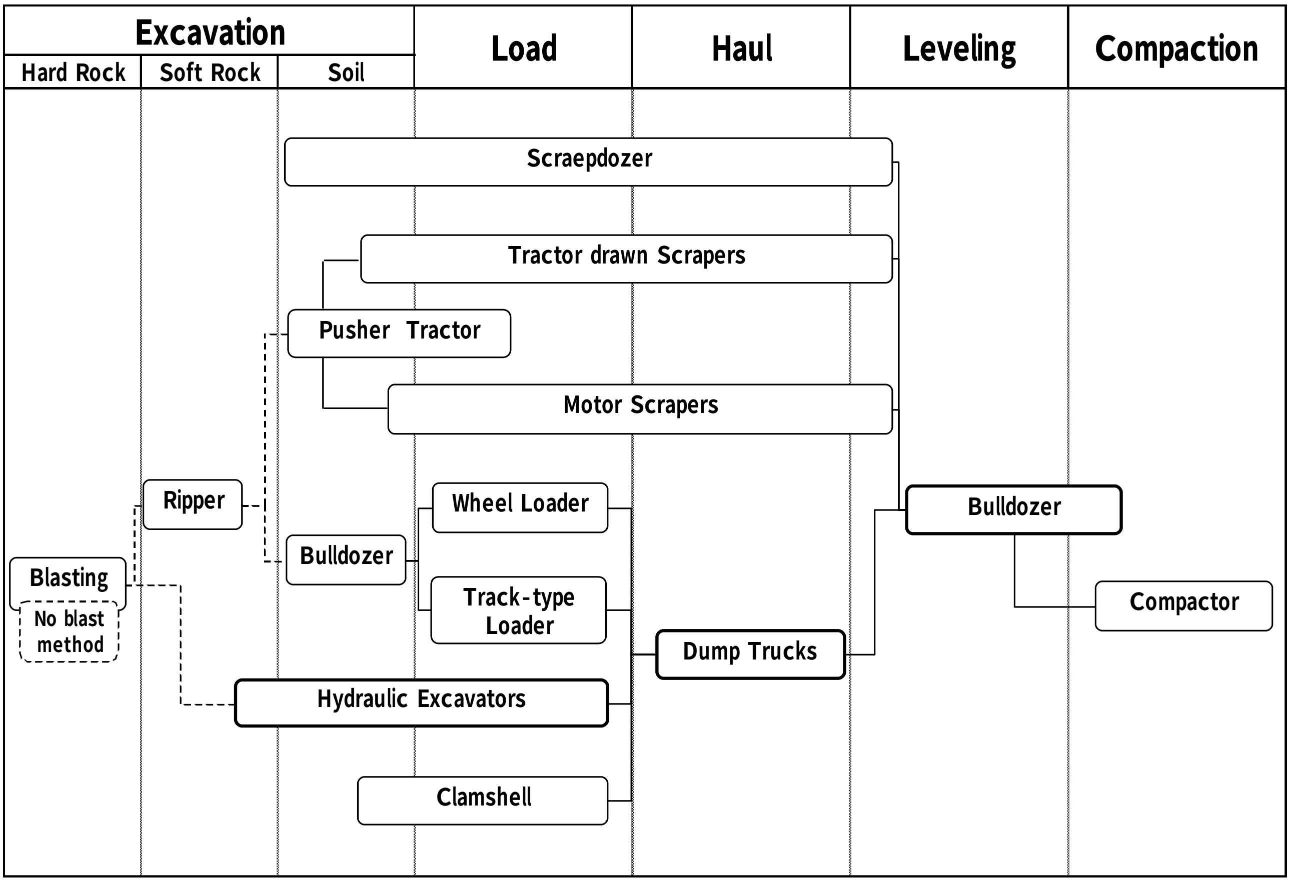


Fig.2 Co-Operation

Table-3 Kind of Work & Typical Co-Operation Equipments

Work	Typical Co-Operation Equipments
Excavating / Loading / Hauling	Bulldozer + Loading equipment + Dump Truck
Spreading / Compacting	Spreading equipment + Compact equipment
Loading / Hauling / Spreading	Scraper + (Pusher)

4. Cost of Earthmoving

The cost of earthmoving is generally shown by cost per working volume as the following formula.

$$C = \frac{P}{Q}$$

Where C : Cost of earthmoving (yen/ m^3)
P : Cost of equipment (yen/h)
Q : Working ability of equipment (m^3/h)

The cost of equipment is consist of following, and has around 30-40% of cost in case of earthmoving for road construction.

Cost of equipment
- Owning Cost
  - Depreciation Cost
  - Maintenance and Repair Costs
  - Tax, Insurance, Storage, etc.
- Operating Cost
  - Operator Costs
  - Fuel and Lubricating Costs
  - Consuming Parts Costs etc.
- Others
  - Set up / Breakdown Costs
  - Transporting Costs etc

Hyd. Rock Spliter MHS900

5. Estimate Production

5.1 Working Ability of a Equipment

The feature of earthmoving is mainly consist of repeat or gathering of simple works. To give an example, loading work of power shovel is consist of excavating, turn, loading to track and return for one cycle.

The working ability, generally shown by working volume per hour and is expressed as the following basic formula.

$$Q = q \cdot n \cdot f \cdot E$$

$$= \frac{60 \cdot q \cdot f \cdot E}{Cm}$$

where

- Q : Production per 60 minute hour(m^3/h)
- q : Payload: heaped capacity (m^3/trip)
- n : Number of cycle (trip/h)
- f : Earth volume conversion factor
- E : Efficiency factor ($E = E_1 \cdot E_2$)
- Cm : Cycle time (min)

E is considered to divide E_1 and E_2 as following, but it is practically difficult to distinguish between E_1 and E_2.

$$E_1 = \frac{Tw}{Tw + To}$$

Where

- E_1 : working time rate
- Tw : Real Working Time
- To : Traveling Time + Idling Time + Waiting Time in Working (within about 10 min) + others
- Tw + To : Operating Time

E_1 depends on earthmoving method, co-operating equipment, working condition, hauling distance, maintenance condition of equipment, etc. (E_1 = 0.6 ～ 0.9)

E_2 is working ability rate that depends on soil condition, weather condition, selection of equipments, operator ability, etc. (E_2 = 0.5 ～ 0.85)

(1) Bulldozer

$$Q = \frac{60 \cdot q \cdot f \cdot E}{Cm}$$

$$= \frac{3600 \times q \times f \times E}{2.2 \times \ell + 15}$$

where ℓ : Hauling (dozing) distance (m)

(2) Tractor drawn Scraper

$$Q = \frac{60 \cdot q \cdot f \cdot E}{Cm}$$

$$= \frac{60 \times q \times f \times E}{1.7 + 0.026 \times \ell}$$

(3) Motor Scraper, Dump Truck

$$Q = \frac{60 \cdot q \cdot f \cdot E}{Cm}$$

$$= \frac{60 \times q \times f \times E}{0.06 \times \frac{\ell_1}{v_1} + 0.06 \times \frac{\ell_2}{v_2} + to}$$

where ℓ_1 : distance of Haul (m)

ℓ_2 : distance of Return (m)

v_1 : velocity of Haul(m)

v_2 : velocity of Return (m)

t_0 : Load, Maneuver and Spread time

(4) Loader, Backhoe

$$Q = \frac{60 \cdot q \cdot f \cdot E}{Cm}$$

$$= \frac{3600 \times q_h \times f \times E}{Cm \times n}$$

where q_h : Hauler payload capacity (m^3/unit)

n : Number of Load

(5) Compactor

$$Q = \frac{S \cdot 1000 \cdot W \cdot h \cdot E}{P} \times f$$

where Q : Compacted Production per 60 minute hour(m^3/h)
S : Compacting Speed (km/h)
W : Compacting Width
h : Compacted lift Thickness
E : Working efficiency (E = E1・ E2)
P : Number of Passes required (trip/layer)
f : Earth volume conversion factor

Working capacity per day (QD) and during term (Qy) are shown as following.

QD = Q x TD

where QD : Working Ability per day (m3/d)
TD : Operating Time per day (h/d)
(TD = .5 - 7 h/d for earthmoving Equipment)

Operating Time		checking, Investment Time	Pause	
Real Working Time	Other Operating time		Recess	Others

Operator working Time

Qy = QD x D

where Qy : Working Ability during term (m3)
D : Operating Day during term (day)
(D depends on rainfall, soil

Required term (DT) for the term
DT=D+(holiday)+(pause day by rainfall)+(pause day by after rainfall)
+(pause day for repair equipment, prepare and settle, etc.)

5.2 Volume Change Characteristics of Soils

Following are the three principal states in which earthmoving material may exit:

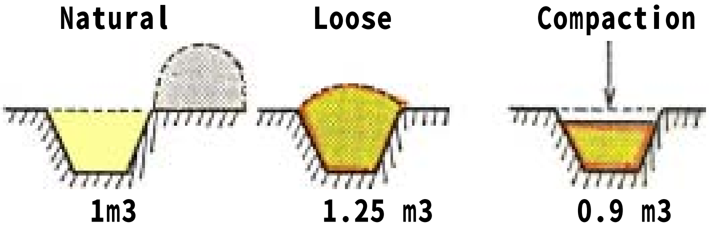
Natural (in-place) :
Soil in its natural state. A unit volume of material is referred to as a bank cubic meter (Bm3).

Loose:
Soil after excavation or loading. A unit volume is referred to as a loose cubic meter (Lm3).

Compacted:
Soil after compaction. A unit volume is referred to as a Compacted cubic meter (Cm3).

Table-4 Conversion factor

Q q	Natural	Excavated	Compacted
Natural (in-place)	1	L	C
Loose	1/L	1	C/L
Compacted	1/C	L/C	1



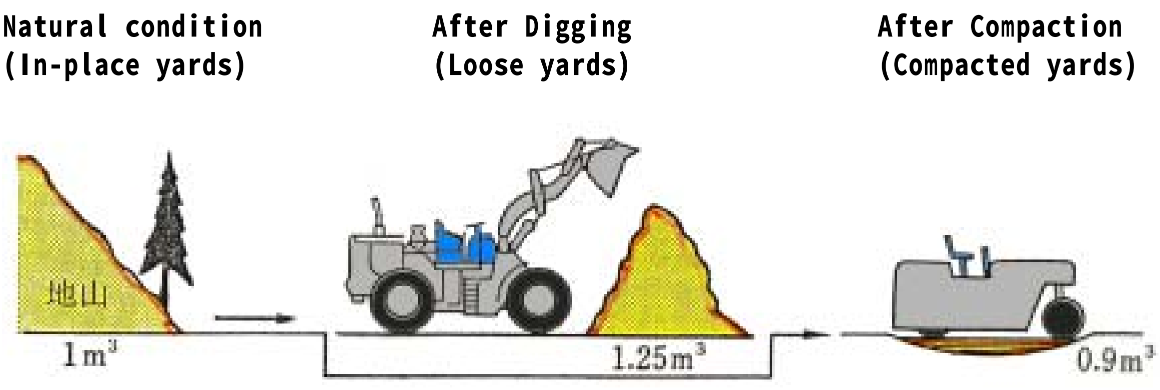


Fig.3 Typical Volume change due to handling

Table-5 Typical soil volume conversion factors

Soil Type		Loose	Compacted
Gravel & Gravelly Soil	Gravel Gravelly Soil	1.20 1.20	0.95 0.90
Sand & Sandy Soil	Sand Sandy Soil	1.20 1.20	0.95 0.90
Cohesive Soil	Cohesive Soil Swampy Cohesive Soil	1.30 1.25	0.90 0.90
Boulder		1.20	1.00
Soft Rock (I)		1.30	1.15
Soft Rock (II)		1.50	1.20
Medium Rock		1.60	1.25
Hard Rock (I)		1.65	1.40

* Rock (II)is harder than Rock(I).

$$L = \frac{\text{Loose volume}}{\text{Bank volum}} \qquad C = \frac{\text{Compaction volume}}{\text{Bank volume}}$$

5.3 Fleet Production

In earthmoving, some co-working equipments are generally used depending on the work to be performed.

a) The working ability of the co-working equipments is determined by the equipment having the minimum working ability in them.

b) The working ability of each equipment should be well balanced.

5.4 Productivity of Combination Work by Oneself

Production of combination work by one equipment, which is for example ripping, and dozing work by one bulldozer is expressed by following formula.

$$Q = \frac{Q1 \times Q2}{Q1 + Q2}$$

where Q : Production of combination work (m^3/h)
Q1: Ripping ability (m^3/h)
Q2: Dozing ability (m^3/h)

6. Soil Condition

6.1 Trafficability

Trafficability refers to the evaluation as how much the ground can bear the traveling of equipment, and is especially important factor for the field of soft soil.

Trafficability of soil is usually evaluated by cone index that is measured by using cone penetrometer.

Table 6 Trafficability

Equipment	Cone index qc (kg/cm2)	Contact pressure of equipment p (kg/cm^2)
Super swampdozer	More than 2	0.15 ～ 0.23
Swampdozer	More than 3	0.22 ～ 0.43
Bulldozer (21t class)	More than 5	0.50 ～ 0.60
Scrapedozer	More than 6	0.41 ～ 0.56
Bulldozer (32t class)	More than 7	0.60 ～ 1.00
Tractor-pulled scraper	More than 7	1.3 ～ 1.4
Motor Scraper	More than 10	4.0 ～ 4.5
Dump Truck	More than 12	3.5 ～ 5.5

$$Qc = \frac{\text{mean resistance force (kg)}}{\text{base area. of cone } (3.24\text{cm}^2)}$$

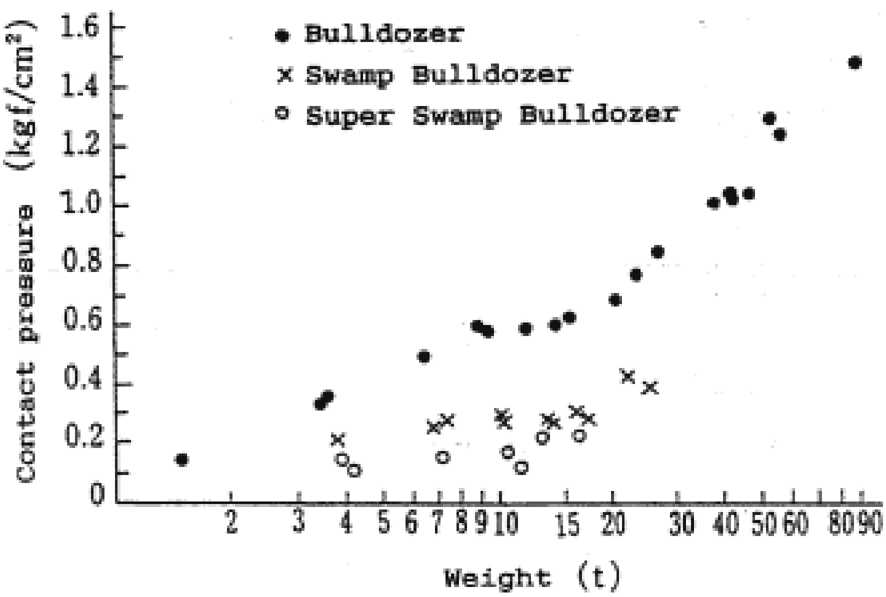


Fig. 4 Contact Pressure of Bulldozer

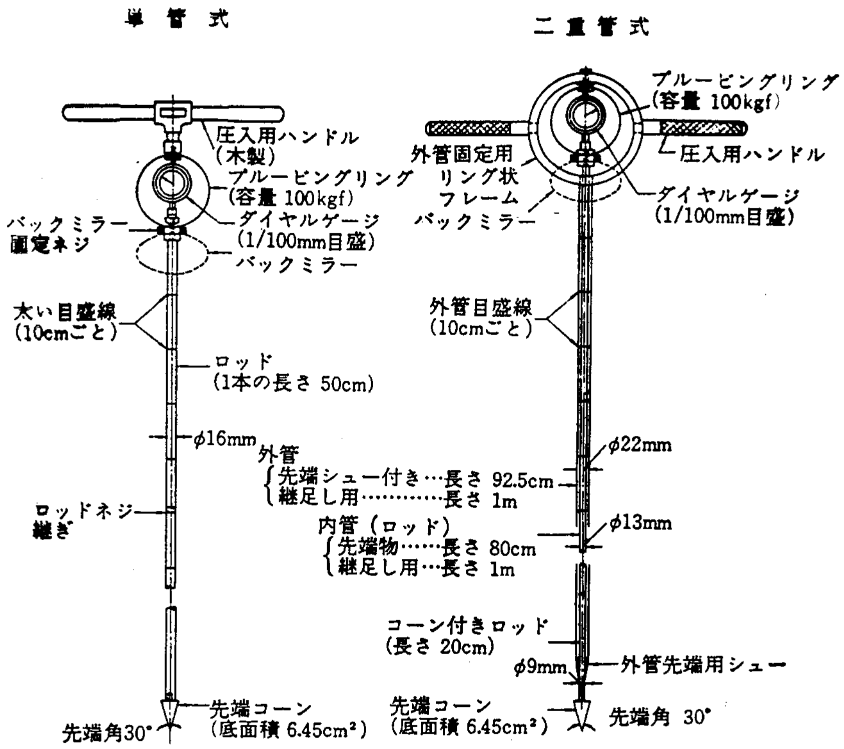


Fig.5 Cone penetrometer

Cone penetrometer

6.2 Excavatability

Table-7 Kinds of soil and equipment

Kinds of soil	Equipments
Sand, Sandy soil	Wheel-type or Track-type tractor --- (loosened) Power shovel, Bulldozer --- (fixed)
Clay, Cohesive soil	Power shovel
Soft rock	Bulldozer with ripper, Rock breaker
Hard rock	Large size bulldozer with ripper (after loosening with dynamite), Rock breaker

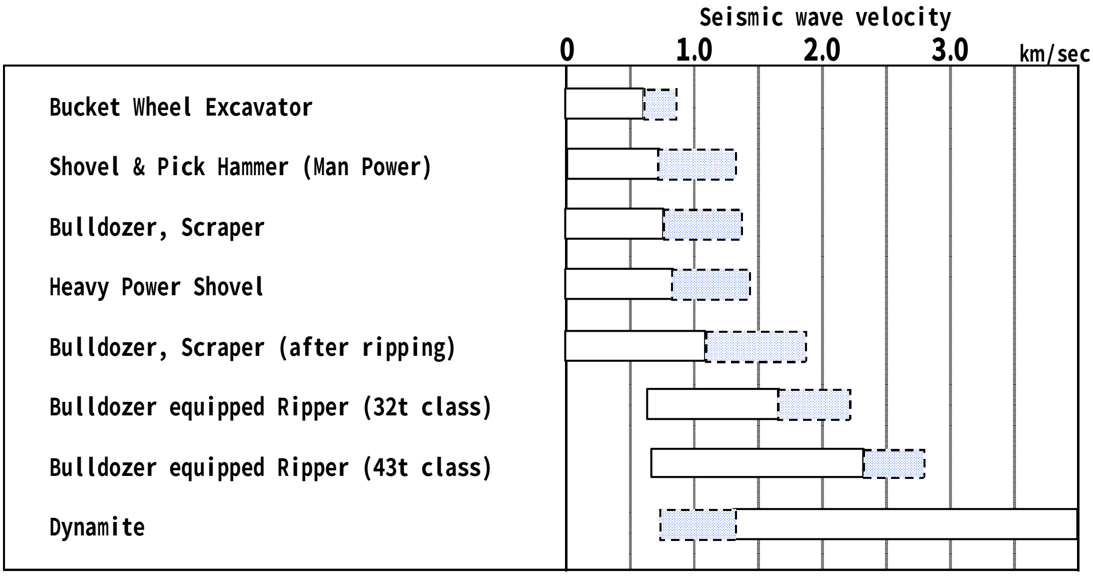


Fig.6 Margin of Earthmoving Equipment

Bucket Wheel Excavator

Backhoe with 5,800kg Rock Breaker (G120)

6.3 Ripperability

The excavation ability of ripper on rock is called ripperability, and is affected by the following factors.

1) Hardness, strength and gap of rock (seismic wave velocity)
2) Direction of crack in rock
3) Ununiformity of rock
4) Working slope
5) Size of bulldozer
6) Number of ripper

Ripperability can be estimated by measuring the seismic wave velocity of rock as one method.
A rock has higher seismic wave velocity, harder or more difficult to excavate in general.

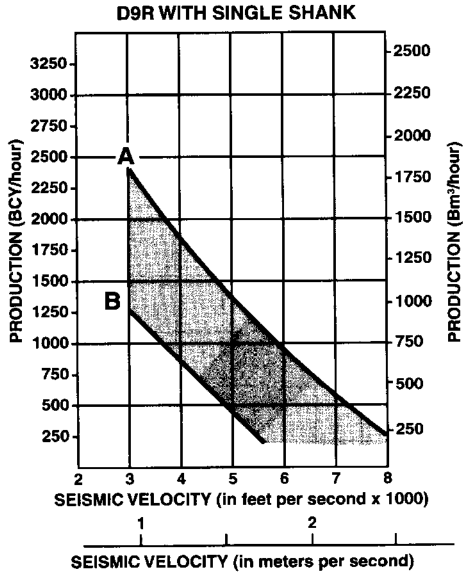


Fig.7 Production estimated graph

D9R Multi or Single Shank No.9 Ripper
Estimated by Seismic Wave Velocities

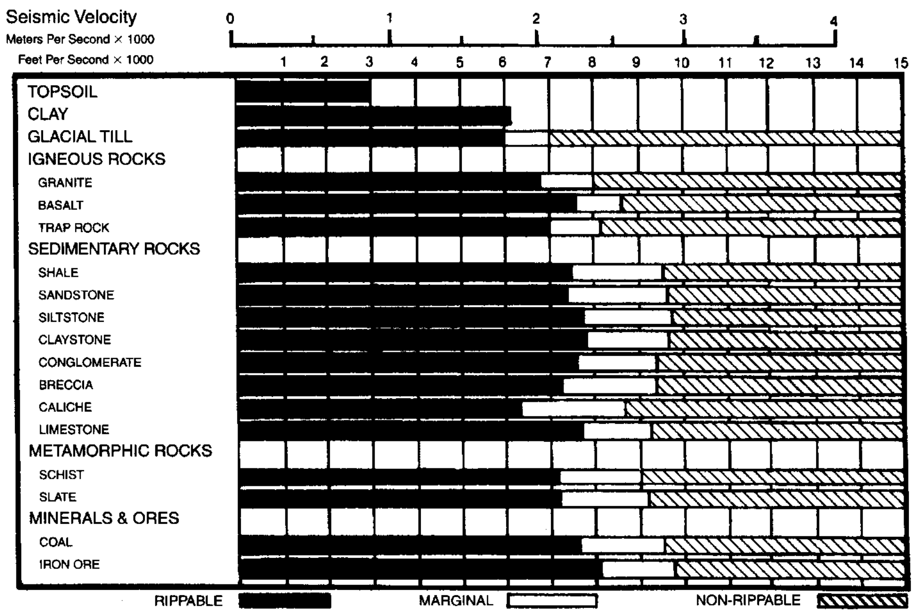


Fig.8 ripperability of rock

103t-Bulldozer with Ripper：CAT D11R

The principle measuring the seismic wave velocity in the field is shown as following.

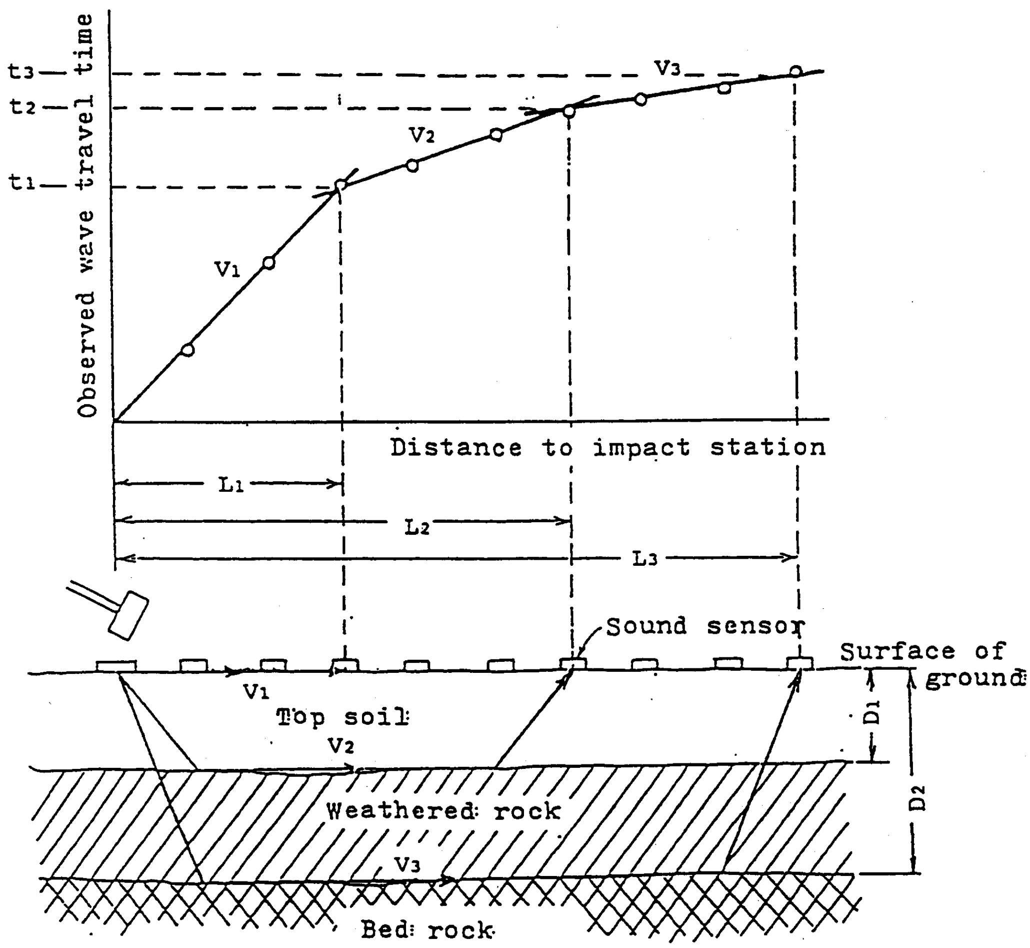


Fig.9 Operation of the refraction seismograph

The thickness of upper layer of a soil/rock system may be computed by using next Equation.

$$D_1 = \frac{L_1}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}}$$

In most construction application we are primarily concerned with the thickness and hardness of the upper soil/rock layer and with the hardness of the second layer. However, in some cases, it may also be desirable to determine the thickness of the second layer and the hardness of the underlying (third) layer. This can be accomplished by using next Equation.

$$D_2 = \frac{L_2}{2}\sqrt{\frac{V_3 - V_2}{V_3 + V_2}} + L_1 \cdot \frac{V_3\sqrt{V_2^2 - V_1^2} - V_2\sqrt{V_3^2 - V_1^2}}{V_1\sqrt{V_3^2 - V_2^2}}$$

6.4 Compactability

The compacting equipment has many kinds of mechanical characteristics such as static, dynamic vibration or impact to perform an effective compacting material.
The adaptability of the various compacting equipments soil is shown as following.

Table-8 Kinds of soil and kinds of compactor

Kinds of compactor / Kinds of soil	Steel Wheel roller	Pneumatic Tire roller	Tampimg foot roller	Vibrating roller	Vibratory Plate compactor	Tamper	Bulldozer	Swampdozer
Rock		○	○	◎	○	○		
Coarse grained sand				○	○	○		
Sand, Sandy soil		◎	○	○	○	○	○	
Clayly gravel, Cohesive soil		○	◎			○		
Soft clay							○	○
Asphalt paving *)	◎	◎		○	○			

*) refernce ◎ suitable ○ usable

The bulldozer and swampdozer are not compacting equipment, are often used for compacting work when they are used for soil spreading work, as in case of constructing a levee.

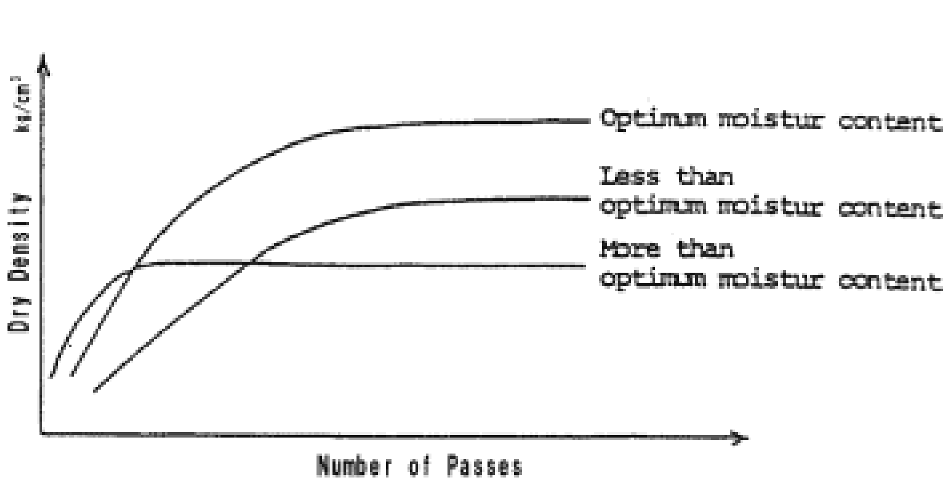
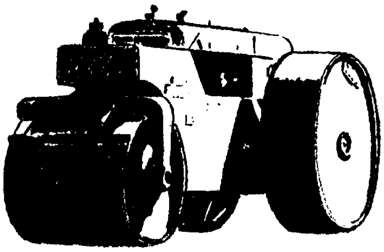
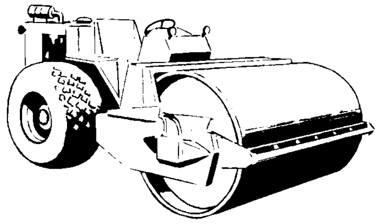


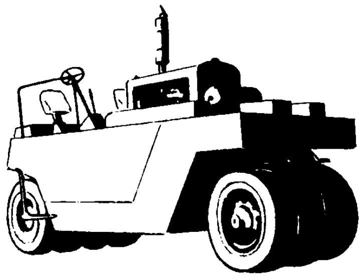
Fig.10 Compactability of soil



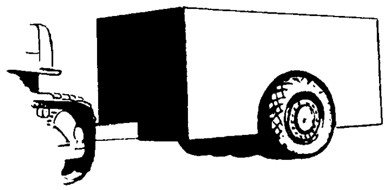
Smooth, steel wheel roller.



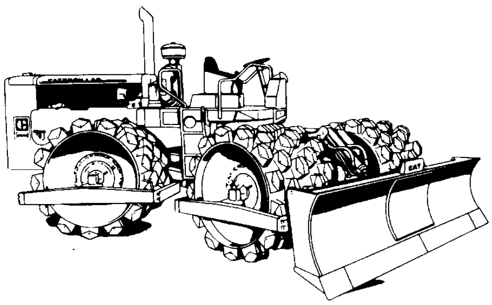
Self-propelled vibrating roller.



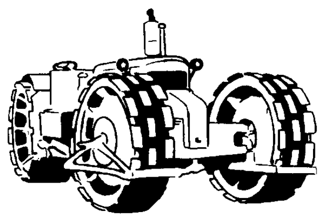
Small, mutli-tired pneumatic roller.



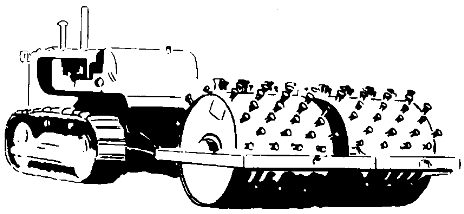
Heavy pneumatic roller.



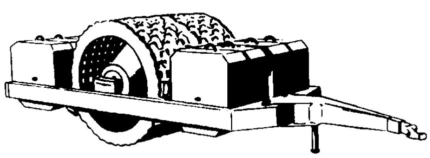
Self-propelled tamping foot roller.



Self-propelled segmented steel wheel roller.



Towed sheepsfoot roller.



Grid roller.

Fig.11 Typical compaction equipment

Vivrating roller for Sloop :SV510DVC

7. Hauling Distance

In general, the relation between hauling distance and unit cost depending on the equipment can be expressed as following.

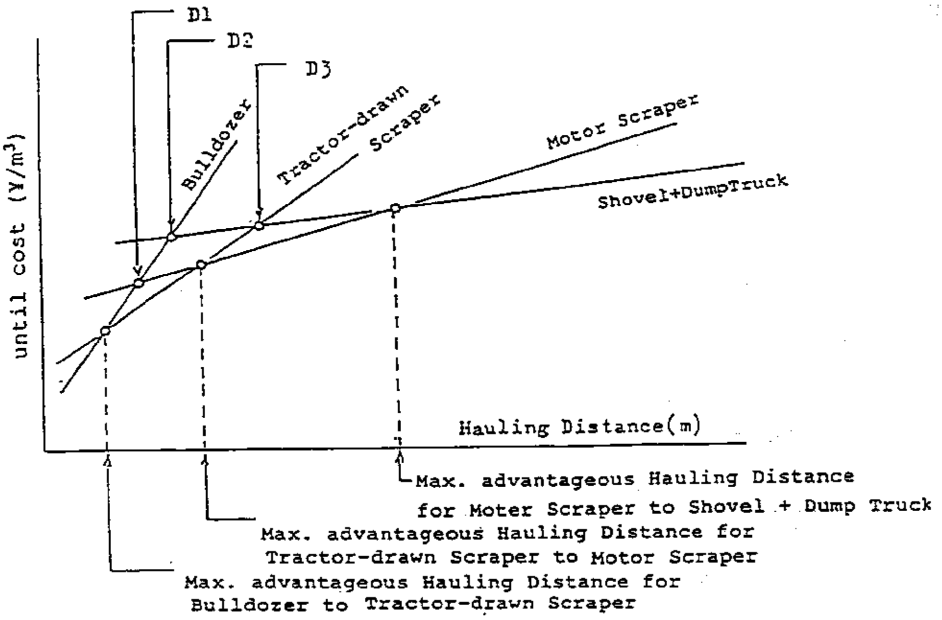


Fig.12 Cost and hauling distance

D1; Max. advantageous Hauling Distance for Bulldozer to Motor Scraper
D2; Max. advantageous Hauling Distance for Bulldozer to Shovel+ Dump Truck
D3: Max. advantageous Hauling Distance for Tractor-drawn Scraper to Shovel+ Dump Truck

Table-9 Economic haul distances

Equipment	Hauling Distance
Bulldozer	Less than 80m
Scrapedozer	40 ～ 250m
Tractor-drawn Scraper	60 ～ 400m
Motor Scraper	300 ～ 2500m
Shovel & Dump Truck	more than 200m

* It is possible to use Loader in case of less than 100m of Hauling Distance.
** In case of 80 ～ 200m of Hauling Distance, using most advantageous equipment comparing with between Bulldozer and Shovel & Dump Truck, etc. according to field condition.

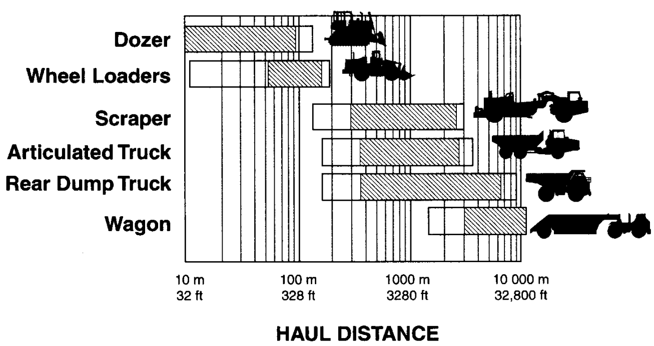


Fig.13 General haul distances for mobile systems

Table-10 Required width of hauling road

Size of Dump Truck	for one way (m)	for double a way (m)
8 ～11 t	4.0 ～ 5.0	8.0 ～ 10.0
20 t	6.4	10.0 ～ 12.0
32 ～ 45 t	7.0 ～ 8.0	14.0 ～ 18.0

(for Dump Truck)

8. Gradeability

Table-11 Gradeability of Equipment

Equipment	Slope (%)
Swamp Bulldozer	40 ～ 55
Bulldozer	35 ～ 40
Tractor-pulled scraper	15 ～ 25
Motor scraper	10
Dump truck	10

In the gradeability of equipment, crawler type is superior in general. The crawler type vehicle has larger tractive force and wider ground contact area, lower gravity center than that of wheel type.

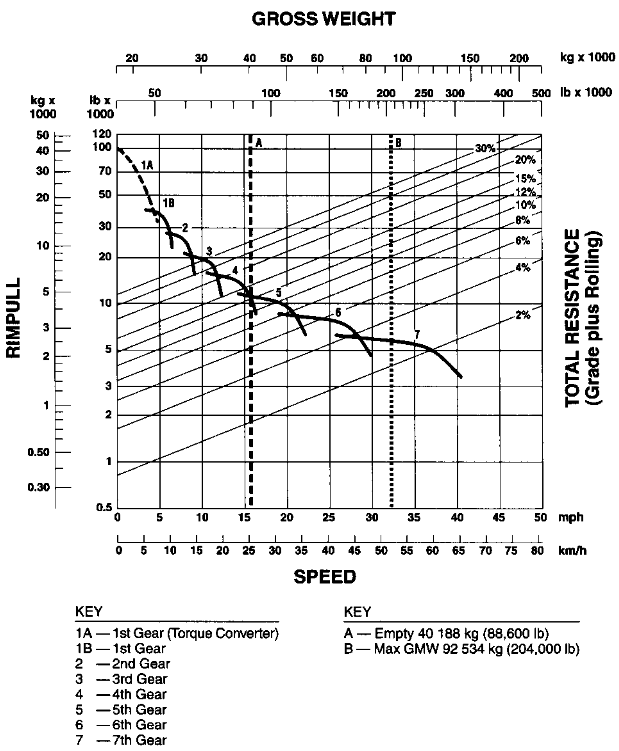


Fig.14 Rimpull-Speed-Gradeability

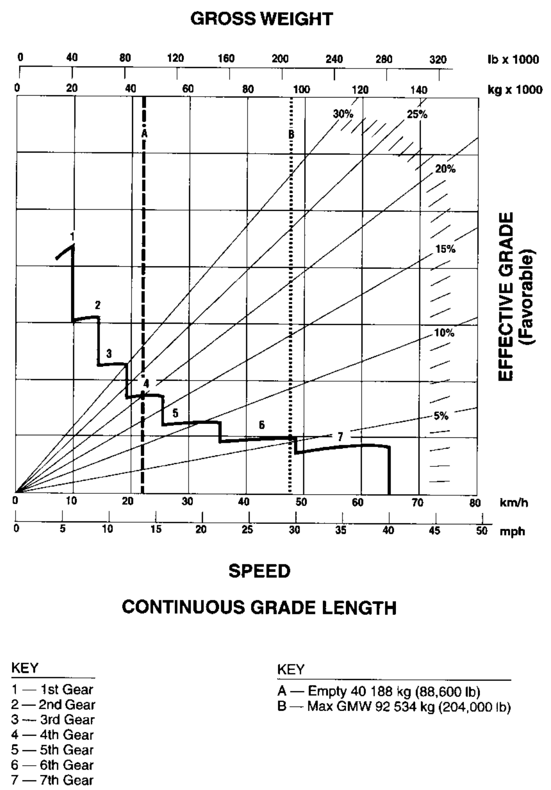


Fig.15 Brake Performance

9. Operating control for equipments

The propriety of control equipment affects greatly the quality, cost, term and safety of construction.

Therefore proper control for equipment is required.

The following must be considered in principle.

(1) To adjust and maintain equipments plentifully
(2) To reduce waiting time for works
(3) To improve operators' ability and enthusiasm
(4) To keep as low as prossible to change equipments throughout the work
(5) To clear off in job fields and to maintain haul road
(6) To keep communication between operators and foremen

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http://www.yamazaki.co.jp/