EGT2
ENGINEERING TRIPOS PART IIA

Tuesday 28 April 2026 14.00 to 15.40

Module 3D9

CONSTRUCTION MANAGEMENT

Answer not more than ***three*** *questions.*

All questions carry the same number of marks.

The ***approximate*** *percentage of marks allocated to each part of a question is indicated in the right margin.*

Write your candidate number ***not*** *your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Attachment: 3D9 Construction Management data sheet (19 pages).
Engineering Data Book

10 minutes reading time is allowed for this paper at the start of the exam.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

You may not remove any stationery from the Examination Room.

1 (a) Name four negative consequences when all work is subcontracted by the general contractor. [20%]

(b) Use the project activities information provided in Table 1 to:

(i) draw their Activity-on-Node diagram. Perform forward pass calculations to determine for each activity the early start time and early finish time. [20%]

(ii) perform backward pass calculations to determine for each activity the total float and free float. Indicate which activities belong to the critical path. [30%]

Table 1 Project activities information

Activity #	**Durations (days)**	**Predecessor Activities: Relationships**	**Resource Demands (Labourers)**
A	5	-	6
B	8	D:FS, C:SF/2	4
C	3	A:FS/3, H:FS	2
D	10	C:FF/-3, H:FS	6
E	6	A:FS, C:SS/3	4
F	10	A:FF/2	2
G	1	A:FS, E:FF/-1, H:SF/6	6
H	7	A:SS/-4, F:FF/2	4
I	2	B:SS/7, G:SF/5	2
J	1	B:SF, I:FS	6

(c) You have eight labourers. Perform resource allocation for the project in Table 1 using the rules presented in lectures. What is the revised total project duration? What is the minimum total number of additional labourers needed to finish the project in less than 33 days? [30%]

2 Design the cut and fill process needed for constructing the D-E road segment shown in the longitudinal profile in Fig. 1. The same process has not been completed for the rest of the road, *i.e.* left of D and right of E. You need to raise or lower the current ABC ground level to the flat D-E. The road width is 16 m. All material inside and outside of segment D-E is dry common earth and suitable for filling. Inside D-E, the average truck total cycle time is 4 min. All borrow/waste soil must be moved to/from a borrow/dump pit, which has its own loader. You have one shovel (580 LCM/hr) to excavate and load material, and fifteen front wheel drive rear dump 20 LCM trucks (Load time (by shovel & loader) = 2 min; weight on drivers: full = 32.7%; empty = 58.5%) to haul material. Assume that the available power of all equipment exceeds their usable rimpull. There are two routes to the pit: Route 1 (L = 4,426 m; max. outbound grade: 34%; total cycle time: 1.47 hrs) is made of dry, soft, rutted dirt. Route 2 (L = 18,834 m; max. outbound grade: 8%, total cycle time: 1.7 hrs) is a dry rutted dirt roadway. The job efficiency is 75%.

(a) What are the volumes of cut, fill, and waste/borrow? [30%]

(b) Are both routes suitable? Explain why. [40%]

(c) Find the excavation and hauling sequence with the shortest total time duration. [30%]

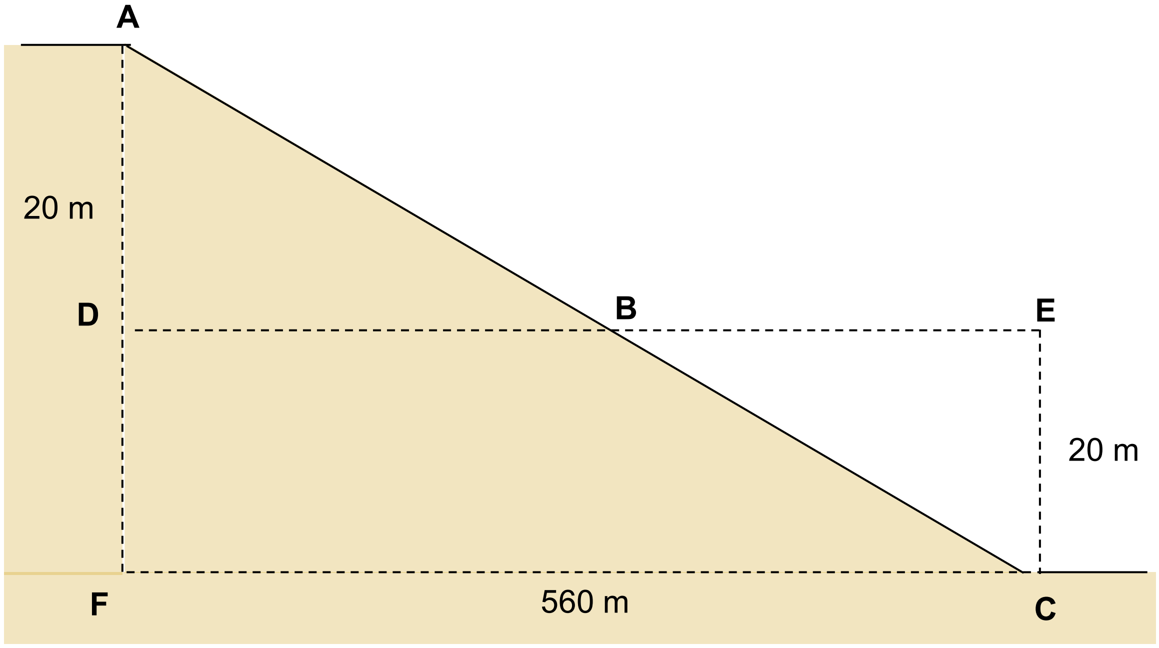

Fig. 1 Longitudinal profile of road segment (not to scale)

3 You are the Engineer advising a client based in a Middle East state on the procurement of a power station to be constructed by a leading international contractor from Europe or North America following a tender exercise. The project includes major civil works, long-lead power-generation equipment, and the integration of advanced mechanical, electrical, and control systems found in modern power stations. Construction and commissioning are planned to last 3 years. The client is inexperienced in large-scale construction and wants clarity on risk management, procurement and contract strategy, and business management considerations. Some project risk events are listed in Table 2 (in no particular order).

(a) Define hazard, risk, and harm. [10%]

(b) Describe the main stages of a risk management process. [15%]

(c) Use a Risk Matrix Approach to identify the risk score of each event. Suggest a mitigation method and identify the risk residual score. [25%]

(d) Which of the major procurement models would be most appropriate for this project? Discuss the potential advantages and disadvantages of the principal models (Traditional, Design & Build, EPC/Turnkey). Based on your recommendation, should the client adopt a standard form contract, and if so which one, or use a bespoke contract? Give reasons for your advice. [50%]

Table 2 Possible risk events

Event	**Description of Previous Company Experience**
Delay in delivery of long-lead power-generation equipment, e.g. turbines, generators, boilers, HV equipment	In the company's experience, such delays occur roughly once every two projects, e.g. long manufacturing cycles, global supply chains, supplier backlogs, shipping disruptions.
Quality defects in civil works requiring rework, e.g. foundations for heavy and vibration-sensitive equipment	The company's records show that this has been reported on every second overseas project, e.g. coordination issues with local subcontractors, different technical standards and construction methods.
Issues between Civil works and Mechanical, Electrical and Plumbing (MEP) installation due to tight tolerances and the need for precise integration between disciplines	The company has observed this on about one-third of large infrastructure projects, e.g. misaligned openings, incorrect embedment, or out-of-sequence work.

4 A General Contractor (GC) is considering a bid for a new middle school. Their direct cost estimate is £21 million.

(a) Using the cost data from 10 previous projects completed by the GC in Table 3, assess whether the GC has historically overestimated or underestimated project costs, explain your reasoning, and calculate a corrected direct cost estimate for the new middle school project. [20%]

(b) Three known competitors (A, B, and C) will submit bids. Assume competitors act independently. The competitor bid ratio distribution is given in Table 4. The total observations per competitor is 50. The GC is considering markups of 8%, 10%, and 12%. Calculate the probability that the GC submits the lowest bid for each markup option. Then, assuming three additional unknown competitors, calculate the expected profit associated with each markup and identify the markup that maximises expected profit. [40%]

(c) Another GC wins the bid with a 6% markup. The project duration is 4 years. Their Budgeted Cost of Work Scheduled (BCWS) for the first year is £6 million. At the end of the first year, their Actual Cost of Work Performed (ACWP) is £6.1 million, and the Cost Performance Index (CPI) is 0.81. Calculate the Schedule Performance Index (SPI), percentage Cost Variance (%CV), and percentage Schedule Variance (%SV) at the end of their first year and discuss their project performance in terms of cost and schedule. [40%]

Table 3 Previous Project Cost Data

Project	Estimated Cost (£m)	Actual Cost (£m)
1	1.20	1.25
2	1.80	1.86
3	2.40	2.52
4	2.90	3.02
5	3.20	3.36
6	3.60	3.55
7	4.10	4.28
8	4.80	4.95
9	5.20	5.10
10	5.80	6.05

Table 4 Competitor Bid Ratio Distribution

Bid Ratio Range *R*	Comp. A	Comp. B	Comp. C
$R \leq 1.02$	2	3	2
$1.02 < R \leq 1.06$	6	7	5
$1.06 < R \leq 1.10$	2	3	2
$R > 1.10$	40	37	41

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University of Cambridge, Engineering Department

Datasheet
Module 3D9
Construction Management

Michaelmas, 2025

Monitoring

Equation for determining the improvement factor (IF):

$$\text{IF (A, N)} = R \times (R_v - R_o - R \times (N_r))$$

where

A = activity designation

N = number of free float days consumed

R = the number of resources used by the activity per day

R_v = number of resource days currently assigned to those days that will be vacated when the activity start date is changed

R_o = number of resource days currently assigned on those days that will be occupied when the activity start date is changed

N_r = the smaller value of the number of days of free float consumed and the duration of the activity

1. Schedule Variance (SV) = Budgeted Cost of Work Performed (BCWP)– Budgeted Cost of Work Scheduled (BCWS)
2. Cost Variance (CV)= Budgeted Cost of Work Performed (BCWP)– Actual Cost of Work Performed (ACWP)
3. %SV = 100 x SV/BCWS
4. %CV = 100 x CV/BCWP
5. Schedule Performance Index (SPI) = BCWP/BCWS
6. Cost Performance Index (CPI) = BCWP/ACWP
7. Earned value = PC X BAC
8. EAC = ACWP + (BAC – BCWP), where BAC – BCWP represents unearned hours

Productivity

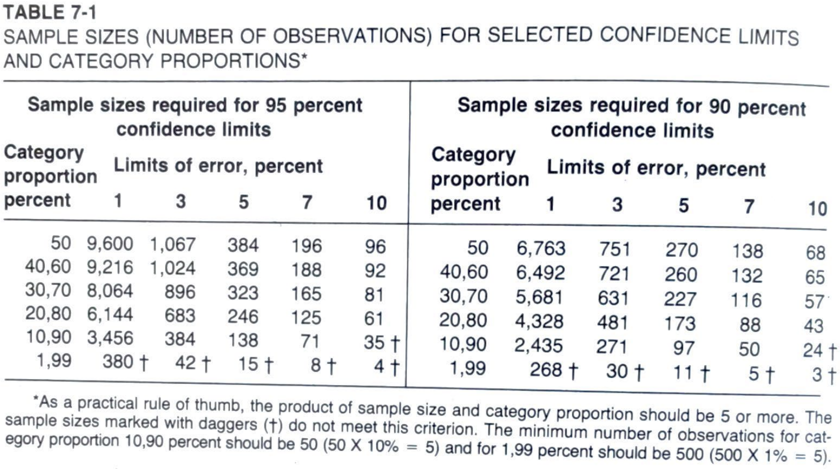


TABLE 7-1

SAMPLE SIZES (NUMBER OF OBSERVATIONS) FOR SELECTED CONFIDENCE LIMITS AND CATEGORY PROPORTIONS*

Sample sizes required for 95 percent confidence limits						Sample sizes required for 90 percent confidence limits					
Category proportion percent	Limits of error, percent					Category proportion percent	Limits of error, percent				
	1	3	5	7	10		1	3	5	7	10
50	9,600	1,067	384	196	96	50	6,763	751	270	138	68
40,60	9,216	1,024	369	188	92	40,60	6,492	721	260	132	65
30,70	8,064	896	323	165	81	30,70	5,681	631	227	116	57
20,80	6,144	683	246	125	61	20,80	4,328	481	173	88	43
10,90	3,456	384	138	71	35 †	10,90	2,435	271	97	50	24 †
1,99	380 †	42 †	15 †	8 †	4 †	1,99	268 †	30 †	11 †	5 †	3 †

*As a practical rule of thumb, the product of sample size and category proportion should be 5 or more. The sample sizes marked with daggers (†) do not meet this criterion. The minimum number of observations for category proportion 10,90 percent should be 50 (50 X 10% = 5) and for 1,99 percent should be 500 (500 X 1% = 5).

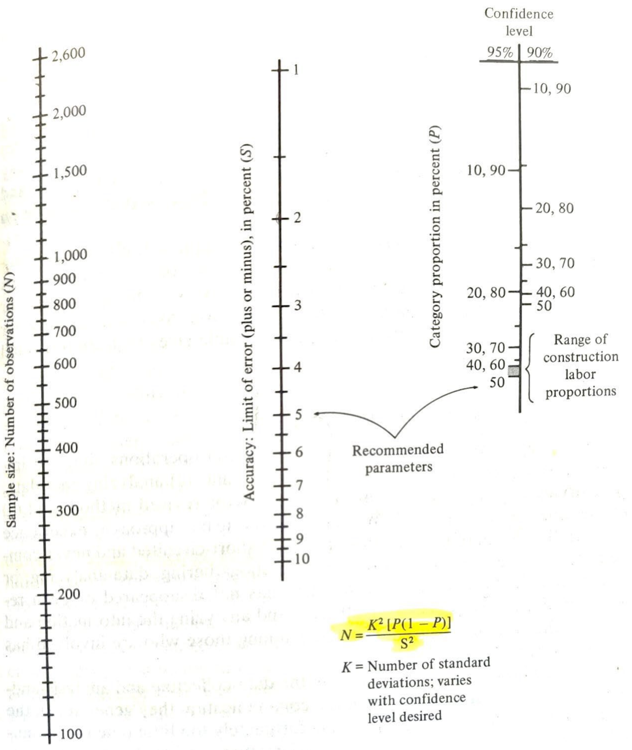
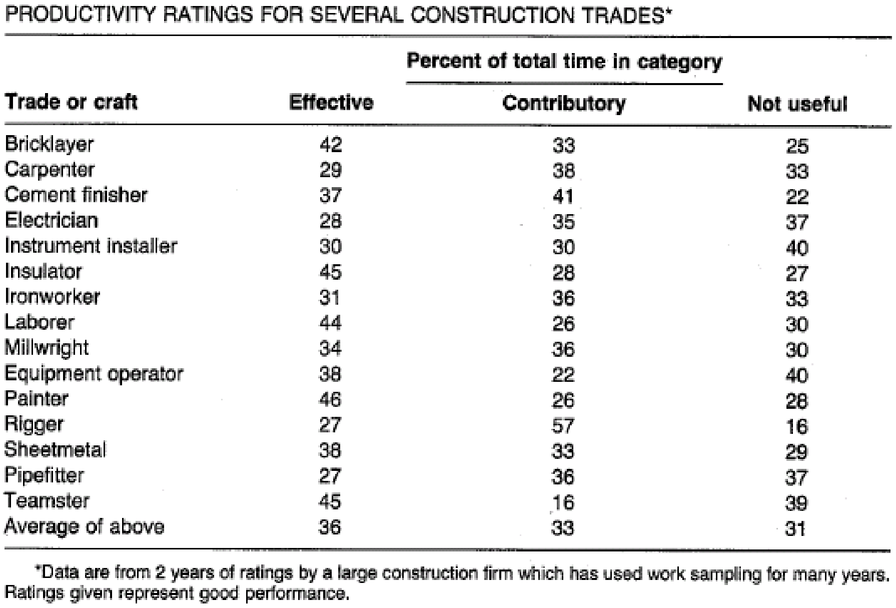


FIGURE 7-1
Nomograph for relating sample size, category proportion, and limit of error for confidence levels of 90 and 95 percent.



PRODUCTIVITY RATINGS FOR SEVERAL CONSTRUCTION TRADES*

Trade or craft	Effective	Percent of total time in category Contributory	Not useful
Bricklayer	42	33	25
Carpenter	29	38	33
Cement finisher	37	41	22
Electrician	28	35	37
Instrument installer	30	30	40
Insulator	45	28	27
Ironworker	31	36	33
Laborer	44	26	30
Millwright	34	36	30
Equipment operator	38	22	40
Painter	46	26	28
Rigger	27	57	16
Sheetmetal	38	33	29
Pipefitter	27	36	37
Teamster	45	16	39
Average of above	36	33	31

*Data are from 2 years of ratings by a large construction firm which has used work sampling for many years. Ratings given represent good performance.

1. Labour utilisation factor

$$Labour\_utilisation\_factor = \frac{effective\_work + \frac{1}{4}essential\_contributory\_work}{total\_observed}$$

2. Total observed = effective + contributory + ineffective
3. Consideration for selecting a Development Approach

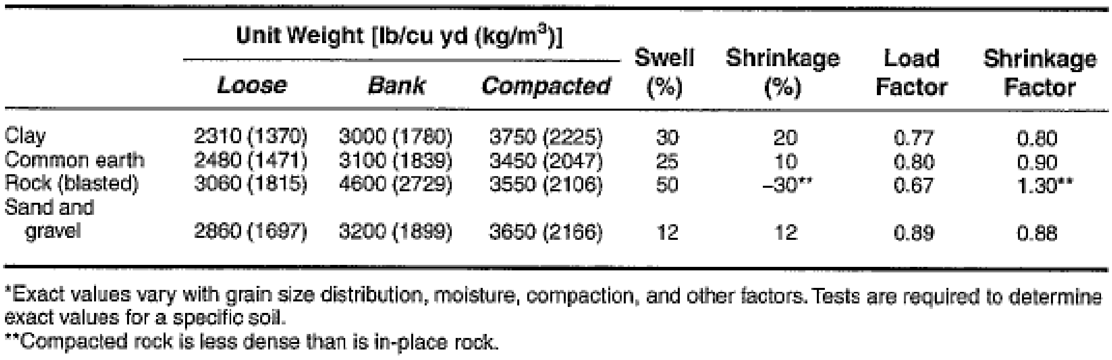
Earthwork Fundamentals

Soil Types	Soil Characteristics:
Boulders (>76mm) Gravel (6 – 76mm) Sand (0.7 – 6mm) Silt (0.002 – 0.7mm) Clay (<0.002mm) Organic (not based on particle size)	Moisture content $Moisture\ content\ (\%) = \frac{moist\ weight - dry\ weight}{dry\ weight} \times 100$
	Liquid limit (LL)
	Plastic limit (PL)
	Plasticity Index (PI) = LL – PL

Soil Volume

	Description	**Conversion**	**Calculation**
Swell (%)	Soil volume increases when excavated	BCM → LCM	$\left(\frac{Weight/bankvol}{Weight/loosevol} - 1\right) \times 100$
Shrinkage (%)	Soil volume decreases when compacted	BCM → CCM	$\left(1 - \frac{Weight/bankvol}{Weight/compactedvol}\right) \times 100$
Load factor	Factor to convert loose volume to bank volume	LCM → BCM	$\frac{Weight/loosevol}{Weight/bankvol} = \frac{1}{1 + swell}$
Shrinkage factor	Factor to convert bank volume to compacted volume	BCM → CCM	$\frac{Weight/bankvol}{Weight/compactedvol} = 1 - shrinkage$

Table 2–5 Typical soil weight and volume change characteristics*

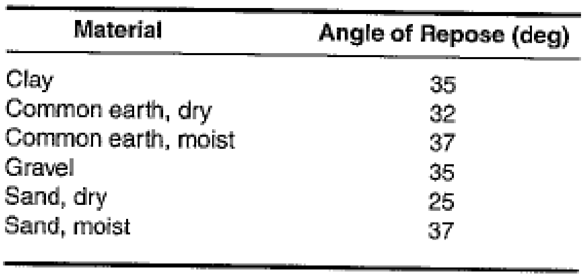


	Unit Weight [lb/cu yd (kg/m^3)]			Swell (%)	Shrinkage (%)	Load Factor	Shrinkage Factor
	Loose	*Bank*	*Compacted*				
Clay	2310 (1370)	3000 (1780)	3750 (2225)	30	20	0.77	0.80
Common earth	2480 (1471)	3100 (1839)	3450 (2047)	25	10	0.80	0.90
Rock (blasted)	3060 (1815)	4600 (2729)	3550 (2106)	50	–30**	0.67	1.30**
Sand and gravel	2860 (1697)	3200 (1899)	3650 (2166)	12	12	0.89	0.88

*Exact values vary with grain size distribution, moisture, compaction, and other factors. Tests are required to determine exact values for a specific soil.

**Compacted rock is less dense than is in-place rock.

Table 2–6 Typical values of angle of repose of excavated soil



Material	Angle of Repose (deg)
Clay	35
Common earth, dry	32
Common earth, moist	37
Gravel	35
Sand, dry	25
Sand, moist	37

Volume of triangular spoil bank	$B = \left(\frac{4V}{L\times\tan R}\right)^{\frac{1}{2}}, H = \frac{B\times\tan R}{2}$
Volume of conical spoil pile	$D = \left(\frac{7.64V}{\tan R}\right)^{\frac{1}{3}}, H = \frac{D}{2}\times\tan R$
	• *B=base width;* • *H=pile height* • *L=pile length* • *R=angle of rep.* • *V=pile volume* • *D=diameter of pile*

Earthwork Volume Estimation

Pits: Volume = Horizontal area x Average depth

Trenches: Volume = Cross-sectional area x Length

Shallow/wide surface areas: Average depth = Sum(depth x weight) / Sum(weights)

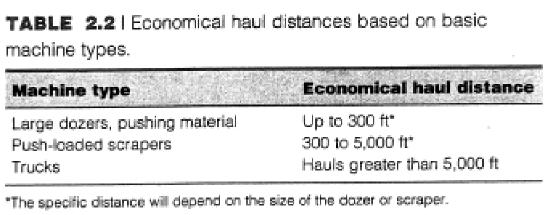
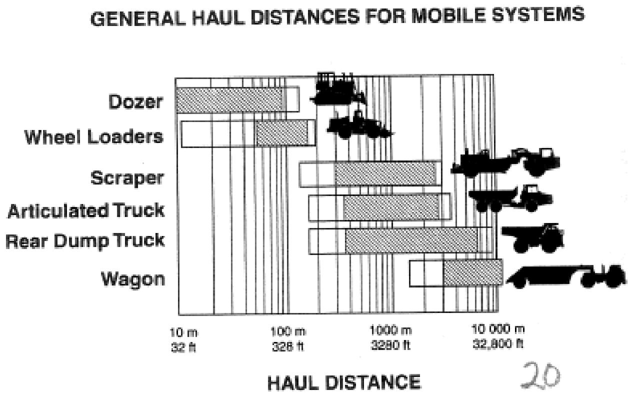


TABLE 2.2 | Economical haul distances based on basic machine types.

Machine type	Economical haul distance
Large dozers, pushing material	Up to 300 ft*
Push-loaded scrapers	300 to 5,000 ft*
Trucks	Hauls greater than 5,000 ft

*The specific distance will depend on the size of the dozer or scraper.



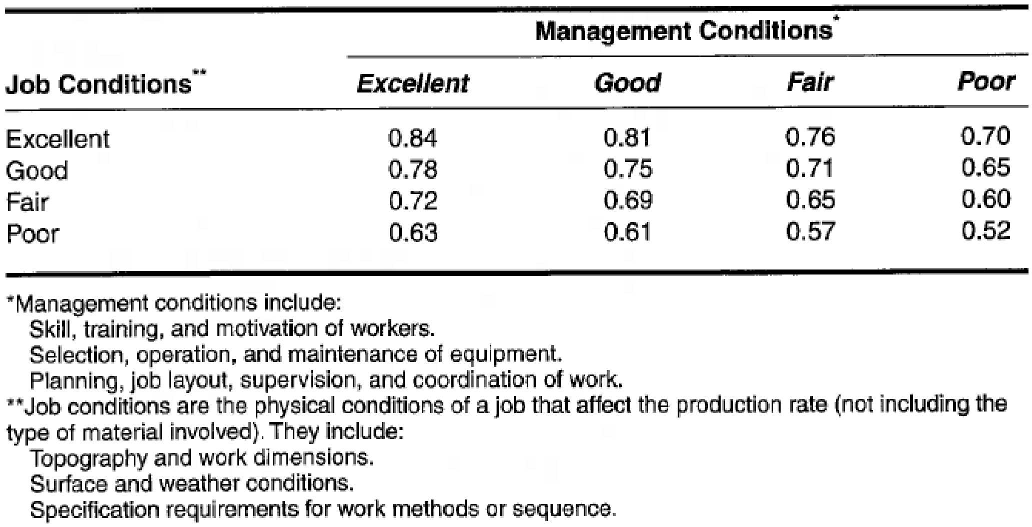
20

Soil Excavation

Excavator Production

$$Production = \frac{volume}{cycle}\times\frac{cycles}{hour}$$

$$Cost\ per\ unit\ of\ production\ = \frac{Equipmentcost\ /\ hour}{Equipmentproduction\ /\ hour}$$



	Management Conditions*			
Job Conditions**	Excellent	Good	Fair	Poor
Excellent	0.84	0.81	0.76	0.70
Good	0.78	0.75	0.71	0.65
Fair	0.72	0.69	0.65	0.60
Poor	0.63	0.61	0.57	0.52

*Management conditions include:
Skill, training, and motivation of workers.
Selection, operation, and maintenance of equipment.
Planning, job layout, supervision, and coordination of work.

**Job conditions are the physical conditions of a job that affect the production rate (not including the type of material involved). They include:
Topography and work dimensions.
Surface and weather conditions.
Specification requirements for work methods or sequence.

When nothing is given, assume Good/Good: 0.75 efficiency

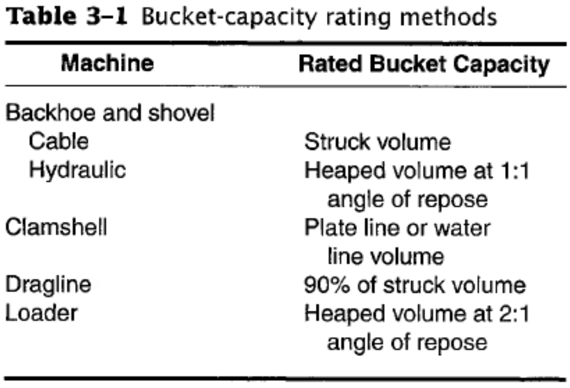
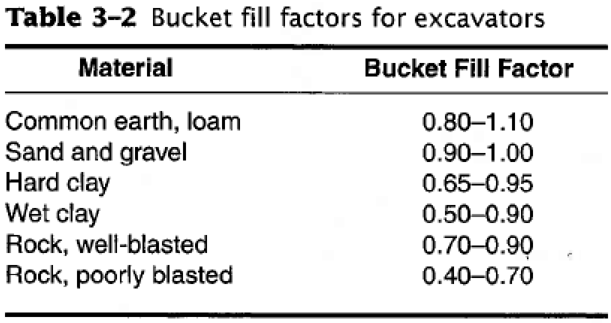
Bucket capacity in LCM	Bucket Load, Fill factor
	

Table 3–1 Bucket-capacity rating methods

Machine	Rated Bucket Capacity
Backhoe and shovel	
Cable	Struck volume
Hydraulic	Heaped volume at 1:1 angle of repose
Clamshell	Plate line or water line volume
Dragline	90% of struck volume
Loader	Heaped volume at 2:1 angle of repose

Table 3–2 Bucket fill factors for excavators

Material	Bucket Fill Factor
Common earth, loam	0.80–1.10
Sand and gravel	0.90–1.00
Hard clay	0.65–0.95
Wet clay	0.50–0.90
Rock, well-blasted	0.70–0.90
Rock, poorly blasted	0.40–0.70

Backhoe Production

Production (LCM/h) = CxSxVxBxE
C = cycles/h (Table 3-3)
S = swing-depth factor (Table 3-4)
V = heaped bucket volume (LCM)
B = bucket fill factor (Table 3-2)
E = job efficiency

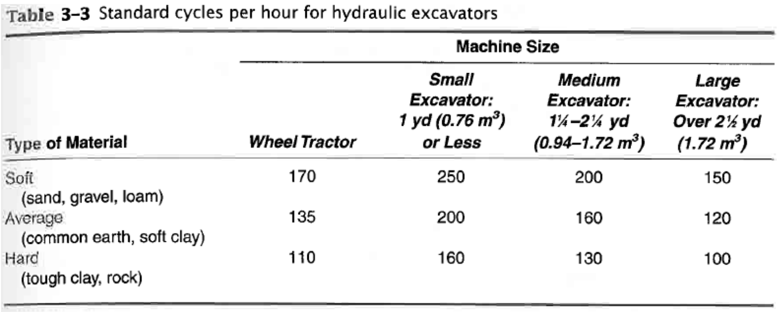


Table 3–3 Standard cycles per hour for hydraulic excavators

	Machine Size			
Type of Material	Wheel Tractor	Small Excavator: 1 yd (0.76 m^3) or Less	Medium Excavator: 1¼–2¼ yd (0.94–1.72 m^3)	Large Excavator: Over 2½ yd (1.72 m^3)
Soft (sand, gravel, loam)	170	250	200	150
Average (common earth, soft clay)	135	200	160	120
Hard (tough clay, rock)	110	160	130	100

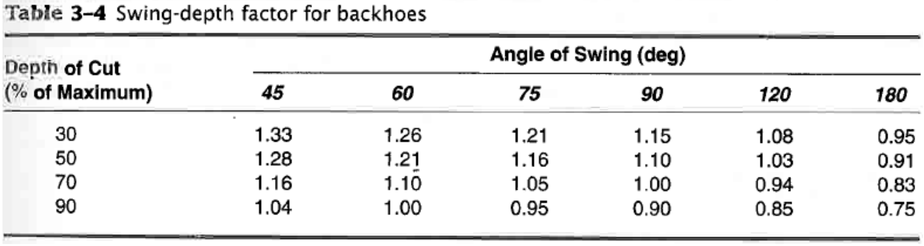


Table 3–4 Swing-depth factor for backhoes

Depth of Cut (% of Maximum)	Angle of Swing (deg)					
	45	60	75	90	120	180
30	1.33	1.26	1.21	1.15	1.08	0.95
50	1.28	1.21	1.16	1.10	1.03	0.91
70	1.16	1.10	1.05	1.00	0.94	0.83
90	1.04	1.00	0.95	0.90	0.85	0.75

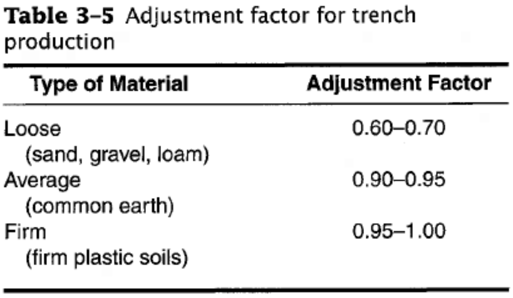


Table 3–5 Adjustment factor for trench production

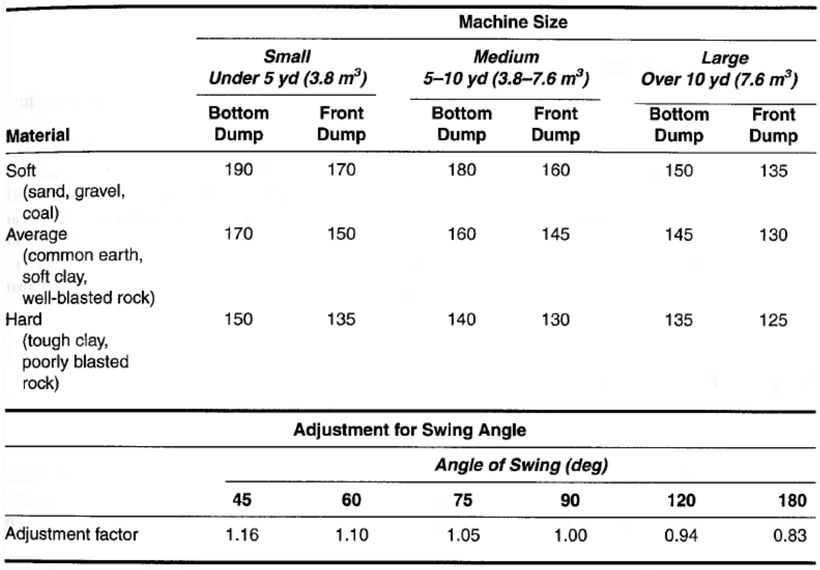
Type of Material	Adjustment Factor
Loose (sand, gravel, loam)	0.60–0.70
Average (common earth)	0.90–0.95
Firm (firm plastic soils)	0.95–1.00

Shovel Production

Production (LCM/h)= CxSxVxBxE

C = cycles/h (Table 3-6)
S = swing factor (Table 3-6)
V = heaped bucket volume (LCM)
B = bucket fill factor (Table 3-2)
E = job efficiency

Table 3–6 Standard cycles per hour for hydraulic shovels



	Machine Size					
	Small Under 5 yd (3.8 m^3)		*Medium 5–10 yd (3.8–7.6 m^3)*		*Large Over 10 yd (7.6 m^3)*	
Material	**Bottom Dump**	**Front Dump**	**Bottom Dump**	**Front Dump**	**Bottom Dump**	**Front Dump**
Soft (sand, gravel, coal)	190	170	180	160	150	135
Average (common earth, soft clay, well-blasted rock)	170	150	160	145	145	130
Hard (tough clay, poorly blasted rock)	150	135	140	130	135	125

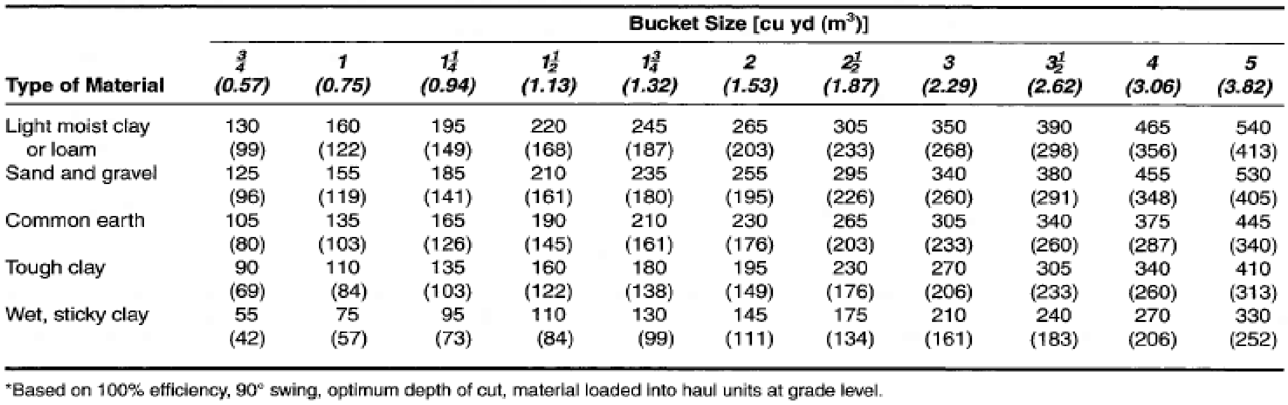
Adjustment for Swing Angle

	Angle of Swing (deg)					
	45	**60**	**75**	**90**	**120**	**180**
Adjustment factor	1.16	1.10	1.05	1.00	0.94	0.83

Dragline Production

Expected production = Ideal output x S/D factor x Efficiency
Must first determine optimum depth and material (Table 3-8)
Divide actual by optimum depth, then use table 3-9

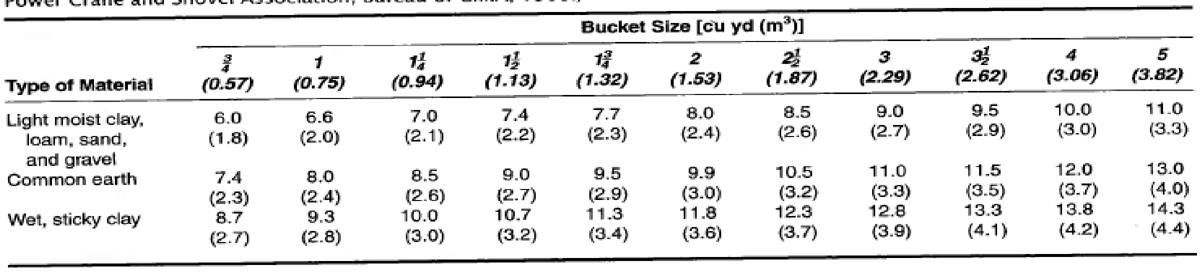
Table 3–7 Ideal dragline output—short boom [BCY/h (BCM/h)]*. (This is a modification of data published in *Technical Bulletin No. 4*, Power Crane and Shovel Association, Bureau of CIMA, 1968.)



	Bucket Size [cu yd (m^3)]										
Type of Material	***¾ (0.57)***	***1 (0.75)***	***1¼ (0.94)***	***1½ (1.13)***	***1¾ (1.32)***	***2 (1.53)***	***2½ (1.87)***	***3 (2.29)***	***3½ (2.62)***	***4 (3.06)***	***5 (3.82)***
Light moist clay or loam	130 (99)	160 (122)	195 (149)	220 (168)	245 (187)	265 (203)	305 (233)	350 (268)	390 (298)	465 (356)	540 (413)
Sand and gravel	125 (96)	155 (119)	185 (141)	210 (161)	235 (180)	255 (195)	295 (226)	340 (260)	380 (291)	455 (348)	530 (405)
Common earth	105 (80)	135 (103)	165 (126)	190 (145)	210 (161)	230 (176)	265 (203)	305 (233)	340 (260)	375 (287)	445 (340)
Tough clay	90 (69)	110 (84)	135 (103)	160 (122)	180 (138)	195 (149)	230 (176)	270 (206)	305 (233)	340 (260)	410 (313)
Wet, sticky clay	55 (42)	75 (57)	95 (73)	110 (84)	130 (99)	145 (111)	175 (134)	210 (161)	240 (183)	270 (206)	330 (252)

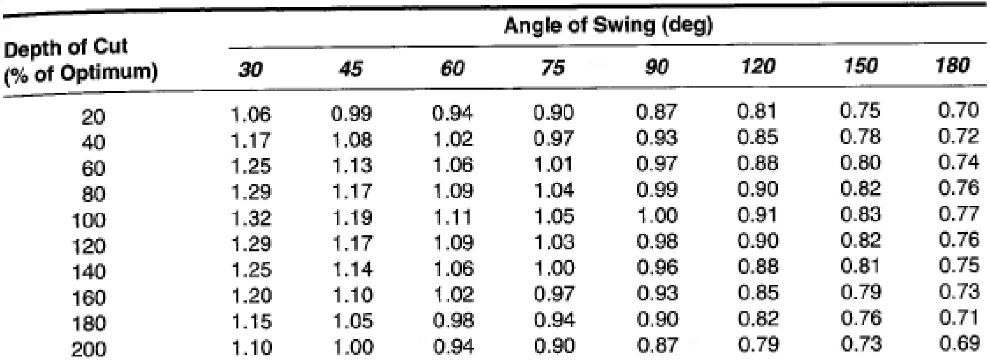
*Based on 100% efficiency, 90° swing, optimum depth of cut, material loaded into haul units at grade level.

Table 3–8 Optimum depth of cut for short boom. (This is a modification of data published in *Technical Bulletin No. 4*, Power Crane and Shovel Association, Bureau of CIMA, 1968.)



	Bucket Size [cu yd (m^3)]										
Type of Material	***¾ (0.57)***	***1 (0.75)***	***1¼ (0.94)***	***1½ (1.13)***	***1¾ (1.32)***	***2 (1.53)***	***2½ (1.87)***	***3 (2.29)***	***3½ (2.62)***	***4 (3.06)***	***5 (3.82)***
Light moist clay, loam, sand, and gravel	6.0 (1.8)	6.6 (2.0)	7.0 (2.1)	7.4 (2.2)	7.7 (2.3)	8.0 (2.4)	8.5 (2.6)	9.0 (2.7)	9.5 (2.9)	10.0 (3.0)	11.0 (3.3)
Common earth	7.4 (2.3)	8.0 (2.4)	8.5 (2.6)	9.0 (2.7)	9.5 (2.9)	9.9 (3.0)	10.5 (3.2)	11.0 (3.3)	11.5 (3.5)	12.0 (3.7)	13.0 (4.0)
Wet, sticky clay	8.7 (2.7)	9.3 (2.8)	10.0 (3.0)	10.7 (3.2)	11.3 (3.4)	11.8 (3.6)	12.3 (3.7)	12.8 (3.9)	13.3 (4.1)	13.8 (4.2)	14.3 (4.4)

Table 3–9 Swing-depth factor for draglines. (This is a modification of data published in *Technical Bulletin No. 4*, Power Crane and Shovel Association, Bureau of CIMA, 1968.)

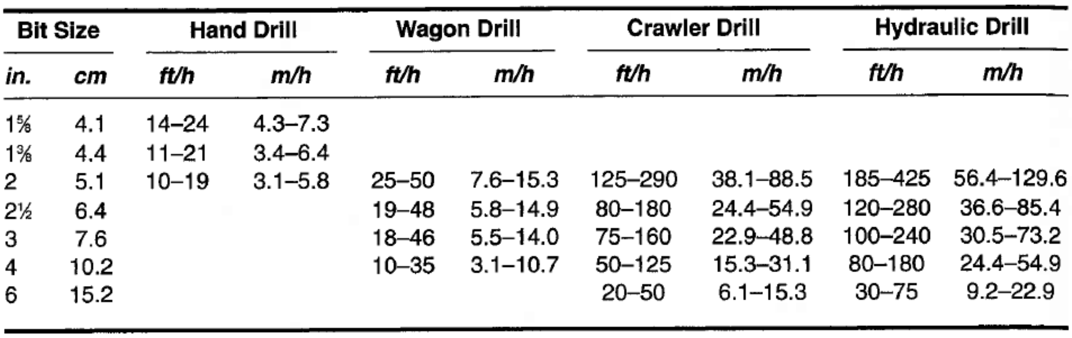


Depth of Cut (% of Optimum)	Angle of Swing (deg)							
	30	*45*	*60*	*75*	*90*	*120*	*150*	*180*
20	1.06	0.99	0.94	0.90	0.87	0.81	0.75	0.70
40	1.17	1.08	1.02	0.97	0.93	0.85	0.78	0.72
60	1.25	1.13	1.06	1.01	0.97	0.88	0.80	0.74
80	1.29	1.17	1.09	1.04	0.99	0.90	0.82	0.76
100	1.32	1.19	1.11	1.05	1.00	0.91	0.83	0.77
120	1.29	1.17	1.09	1.03	0.98	0.90	0.82	0.76
140	1.25	1.14	1.06	1.00	0.96	0.88	0.81	0.75
160	1.20	1.10	1.02	0.97	0.93	0.85	0.79	0.73
180	1.15	1.05	0.98	0.94	0.90	0.82	0.76	0.71
200	1.10	1.00	0.94	0.90	0.87	0.79	0.73	0.69

Rock Excavation

Drill Production

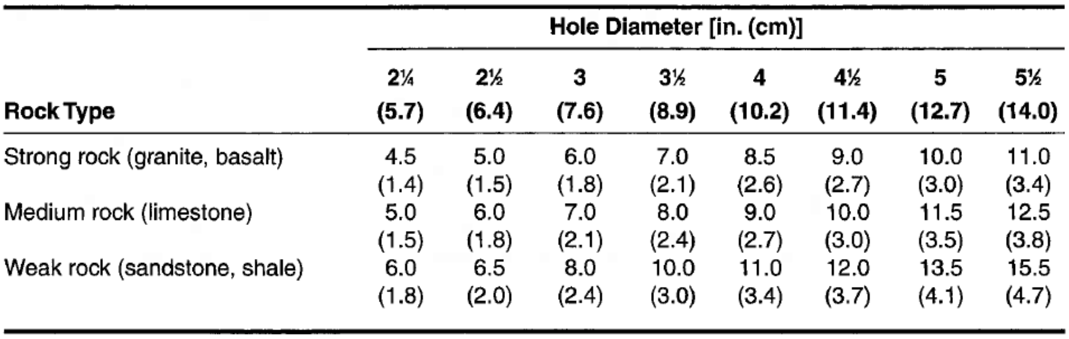
Table 6–3 Representative drilling rates (carbide bit)



Bit Size		Hand Drill		Wagon Drill		Crawler Drill		Hydraulic Drill	
in.	*cm*	*ft/h*	*m/h*	*ft/h*	*m/h*	*ft/h*	*m/h*	*ft/h*	*m/h*
1⅝	4.1	14–24	4.3–7.3						
1⅜	4.4	11–21	3.4–6.4						
2	5.1	10–19	3.1–5.8	25–50	7.6–15.3	125–290	38.1–88.5	185–425	56.4–129.6
2½	6.4			19–48	5.8–14.9	80–180	24.4–54.9	120–280	36.6–85.4
3	7.6			18–46	5.5–14.0	75–160	22.9–48.8	100–240	30.5–73.2
4	10.2			10–35	3.1–10.7	50–125	15.3–31.1	80–180	24.4–54.9
6	15.2					20–50	6.1–15.3	30–75	9.2–22.9

Drilling Patterns – Blasting

Table 6–4 Typical drill hole spacing (rectangular pattern) [ft (m)]



	Hole Diameter [in. (cm)]							
Rock Type	**2¼ (5.7)**	**2½ (6.4)**	**3 (7.6)**	**3½ (8.9)**	**4 (10.2)**	**4½ (11.4)**	**5 (12.7)**	**5½ (14.0)**
Strong rock (granite, basalt)	4.5 (1.4)	5.0 (1.5)	6.0 (1.8)	7.0 (2.1)	8.5 (2.6)	9.0 (2.7)	10.0 (3.0)	11.0 (3.4)
Medium rock (limestone)	5.0 (1.5)	6.0 (1.8)	7.0 (2.1)	8.0 (2.4)	9.0 (2.7)	10.0 (3.0)	11.5 (3.5)	12.5 (3.8)
Weak rock (sandstone, shale)	6.0 (1.8)	6.5 (2.0)	8.0 (2.4)	10.0 (3.0)	11.0 (3.4)	12.0 (3.7)	13.5 (4.1)	15.5 (4.7)

Drilling Patterns - Rectangular

Volume of blasted rock: $Volume/hole = S^2 \times H$

S = pattern spacing

H = effective hole depth

Usually 90% of actual

Volume per m of hole: $\frac{Volume}{m\ of\ hole} = \frac{Volume/hole}{Drilled\ depth}$

Explosives table

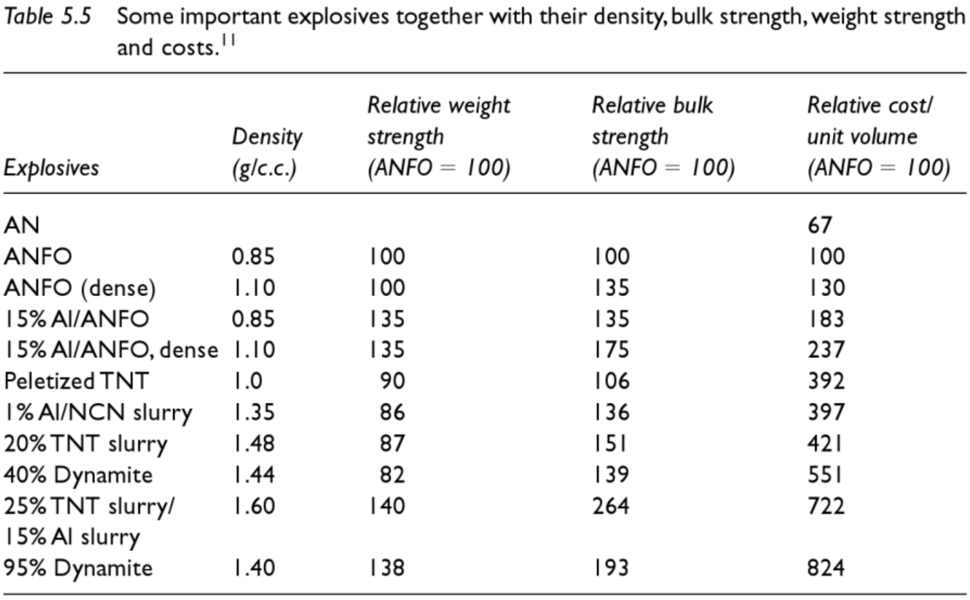


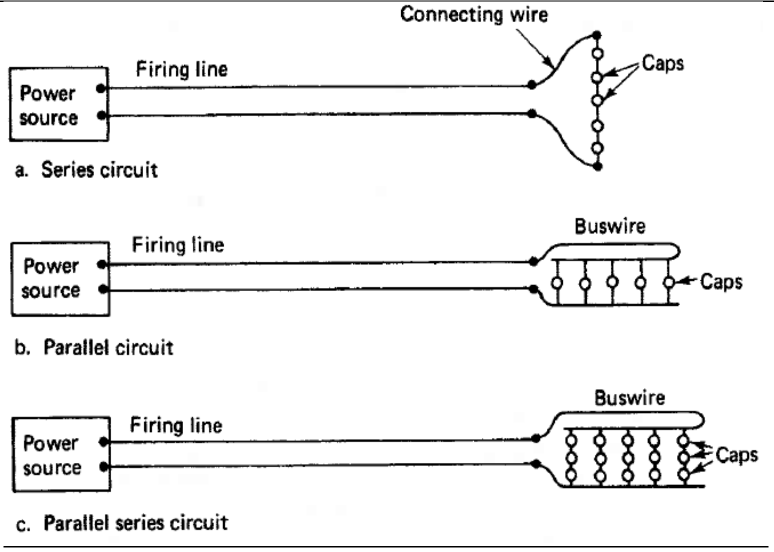
Table 5.5 Some important explosives together with their density, bulk strength, weight strength and costs.[11]

Explosives	Density (g/c.c.)	Relative weight strength (ANFO = 100)	Relative bulk strength (ANFO = 100)	Relative cost/ unit volume (ANFO = 100)
AN				67
ANFO	0.85	100	100	100
ANFO (dense)	1.10	100	135	130
15% Al/ANFO	0.85	135	135	183
15% Al/ANFO, dense	1.10	135	175	237
Peletized TNT	1.0	90	106	392
1% Al/NCN slurry	1.35	86	136	397
20% TNT slurry	1.48	87	151	421
40% Dynamite	1.44	82	139	551
25% TNT slurry/ 15% Al slurry	1.60	140	264	722
95% Dynamite	1.40	138	193	824

Electric Blasting Circuits

Blasting caps circuits connected

- *In series (S)*
- *Parallel (P)*
- *Parallel-series (PS)*



a. Series circuit

b. Parallel circuit

c. Parallel series circuit

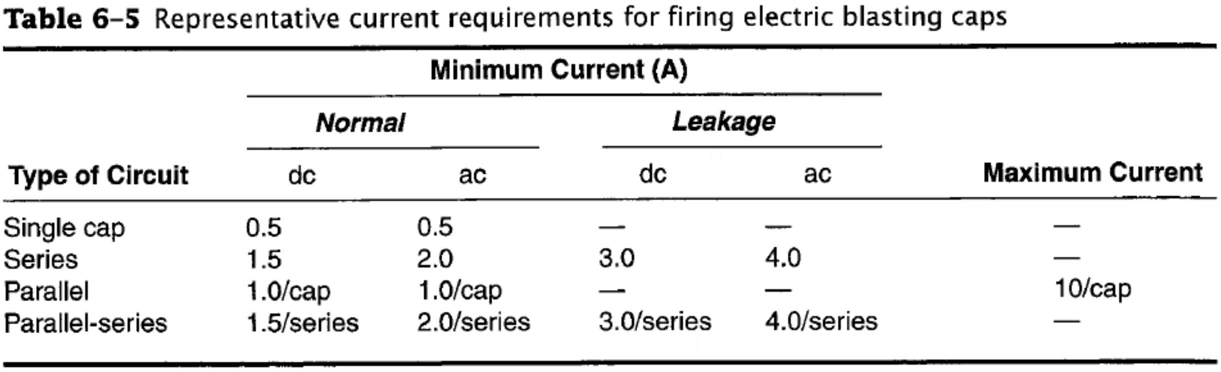


Table 6–5 Representative current requirements for firing electric blasting caps

	Minimum Current (A)				
	Normal		*Leakage*		
Type of Circuit	dc	ac	dc	ac	**Maximum Current**
Single cap	0.5	0.5	—	—	—
Series	1.5	2.0	3.0	4.0	—
Parallel	1.0/cap	1.0/cap	—	—	10/cap
Parallel-series	1.5/series	2.0/series	3.0/series	4.0/series	—

$$Voltage(volts) = Current(amperes) \times Resistance(ohms)$$

$$E = IR$$

Circuit resistance:

$$R_c = \frac{\#caps / series \times Resistance / cap}{\#\,parallel\ branches}$$

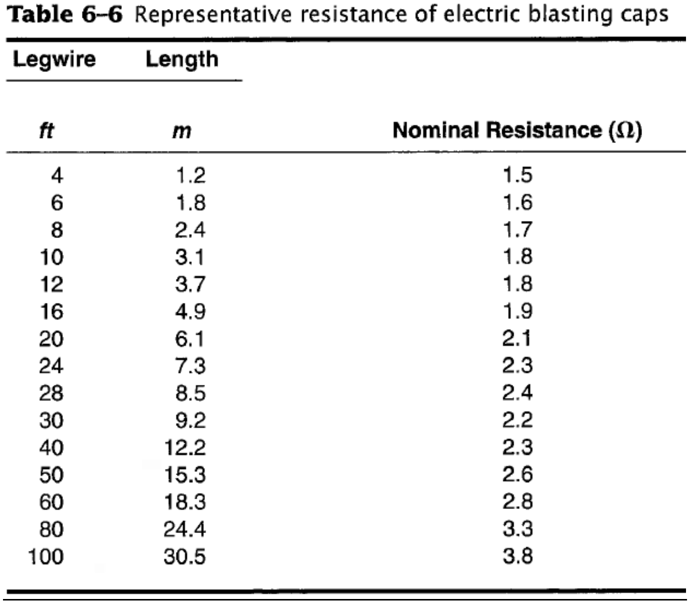


Table 6–6 Representative resistance of electric blasting caps

Legwire Length ft	m	Nominal Resistance (Ω)
4	1.2	1.5
6	1.8	1.6
8	2.4	1.7
10	3.1	1.8
12	3.7	1.8
16	4.9	1.9
20	6.1	2.1
24	7.3	2.3
28	8.5	2.4
30	9.2	2.2
40	12.2	2.3
50	15.3	2.6
60	18.3	2.8
80	24.4	3.3
100	30.5	3.8

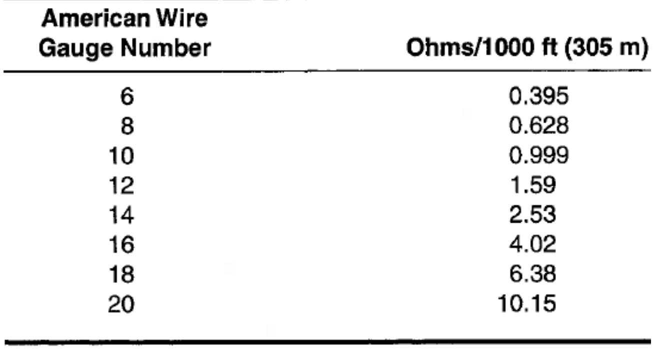


Table 6–7 Resistance of solid copper wire

American Wire Gauge Number	Ohms/1000 ft (305 m)
6	0.395
8	0.628
10	0.999
12	1.59
14	2.53
16	4.02
18	6.38
20	10.15

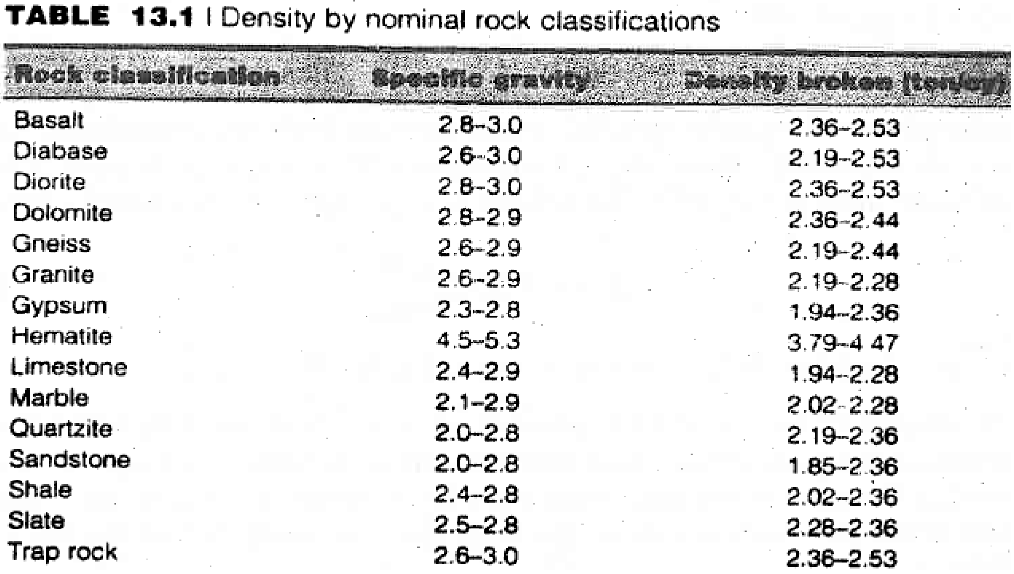


TABLE 13.1 I Density by nominal rock classifications

Rock classification	Specific gravity	Density broken (ton/cy)
Basalt	2.8–3.0	2.36–2.53
Diabase	2.6–3.0	2.19–2.53
Diorite	2.8–3.0	2.36–2.53
Dolomite	2.8–2.9	2.36–2.44
Gneiss	2.6–2.9	2.19–2.44
Granite	2.6–2.9	2.19–2.28
Gypsum	2.3–2.8	1.94–2.36
Hematite	4.5–5.3	3.79–4 47
Limestone	2.4–2.9	1.94–2.28
Marble	2.1–2.9	2.02–2.28
Quartzite	2.0–2.8	2.19–2.36
Sandstone	2.0–2.8	1.85–2.36
Shale	2.4–2.8	2.02–2.36
Slate	2.5–2.8	2.28–2.36
Trap rock	2.6–3.0	2.36–2.53

Burden

$$B = \left(\frac{0.25 \times SG_e}{SG_r} + 0.176\right) D_e$$

B = burden (m)

SG_e = explosive specific gravity

In imperial units:

$$B = \left(\frac{2SG_e}{SG_r} + 1.5\right) D_e$$

SG_r = rock specific gravity (Table 13.1)

D_e = explosive diameter (cm)

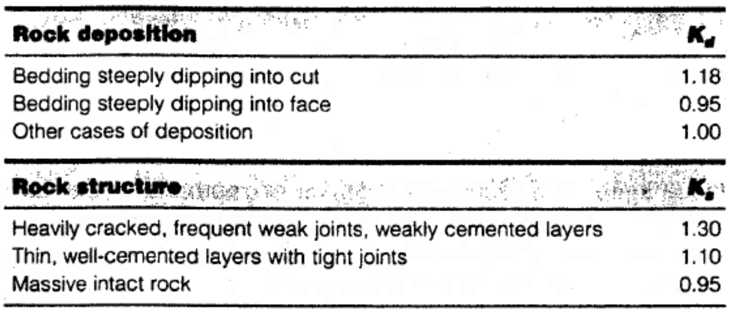
St_v = relative strength compared to ANFO=100

$$B = 0.0804 \times D_e \times \sqrt[3]{\frac{St_v}{SG_r}}$$

In imperial units:

$$B = 0.67 D_e \sqrt[3]{\frac{St_v}{SG_r}}$$

TABLE 13.2 | Burden distance correction factors



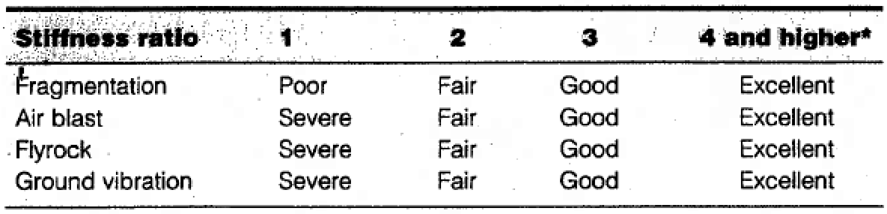
Rock deposition	***K_d***
Bedding steeply dipping into cut	1.18
Bedding steeply dipping into face	0.95
Other cases of deposition	1.00
Rock structure	***K_s***
Heavily cracked, frequent weak joints, weakly cemented layers	1.30
Thin, well-cemented layers with tight joints	1.10
Massive intact rock	0.95

Correction factors for non-homogeneous rock (Table 13.2):

$$B_{corrected} = B \times K_d \times K_s$$

Stiffness ratio = bench height/burden

TABLE 13.3 | Stiffness ratio's effect on blasting factors



Stiffness ratio	**1**	**2**	**3**	**4 and higher***
Fragmentation	Poor	Fair	Good	Excellent
Air blast	Severe	Fair	Good	Excellent
Flyrock	Severe	Fair	Good	Excellent
Ground vibration	Severe	Fair	Good	Excellent

*Stiffness ratios above 4 yield no increase in benefit.

Stemming: Ideal average particle diameter = 0.05 x hole diameter

Ideal = 0.7 to 1.3 times the burden

$$T = 0.7 \times B$$

Subdrilling J: *Ranges from 0.2B to 0.5B*

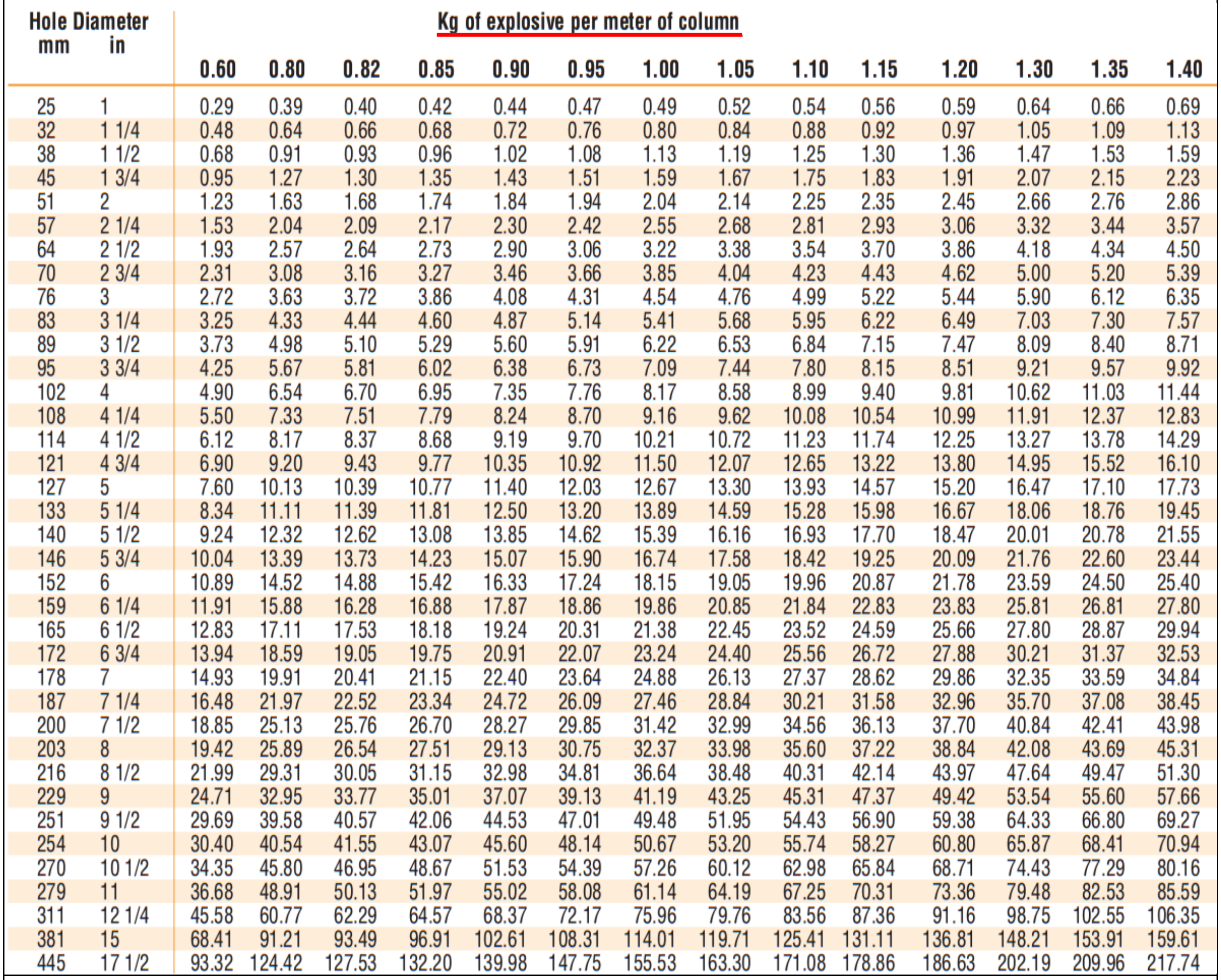
Design cases:

(1) Instant, 1<SR<4 • S = spacing • L = bench height	(1) $S = \frac{L+2B}{3}$
(2) Instant, SR>=4	(2) $S = 2B$
(3) Delayed, 1<SR<4	(3) $S = \frac{L+7B}{8}$
(4) Delayed, SR>=4	(4) $S = 1.4B$

Powder column length = L – stemming + subdrilling

Explosive weight = length x loading density

Powder factor = explosive weight / affected volume



Hole Diameter		Kg of explosive per meter of column													
mm	in	0.60	0.80	0.82	0.85	0.90	0.95	1.00	1.05	1.10	1.15	1.20	1.30	1.35	1.40
25	1	0.29	0.39	0.40	0.42	0.44	0.47	0.49	0.52	0.54	0.56	0.59	0.64	0.66	0.69
32	1 1/4	0.48	0.64	0.66	0.68	0.72	0.76	0.80	0.84	0.88	0.92	0.97	1.05	1.09	1.13
38	1 1/2	0.68	0.91	0.93	0.96	1.02	1.08	1.13	1.19	1.25	1.30	1.36	1.47	1.53	1.59
45	1 3/4	0.95	1.27	1.30	1.35	1.43	1.51	1.59	1.67	1.75	1.83	1.91	2.07	2.15	2.23
51	2	1.23	1.63	1.68	1.74	1.84	1.94	2.04	2.14	2.25	2.35	2.45	2.66	2.76	2.86
57	2 1/4	1.53	2.04	2.09	2.17	2.30	2.42	2.55	2.68	2.81	2.93	3.06	3.32	3.44	3.57
64	2 1/2	1.93	2.57	2.64	2.73	2.90	3.06	3.22	3.38	3.54	3.70	3.86	4.18	4.34	4.50
70	2 3/4	2.31	3.08	3.16	3.27	3.46	3.66	3.85	4.04	4.23	4.43	4.62	5.00	5.20	5.39
76	3	2.72	3.63	3.72	3.86	4.08	4.31	4.54	4.76	4.99	5.22	5.44	5.90	6.12	6.35
83	3 1/4	3.25	4.33	4.44	4.60	4.87	5.14	5.41	5.68	5.95	6.22	6.49	7.03	7.30	7.57
89	3 1/2	3.73	4.98	5.10	5.29	5.60	5.91	6.22	6.53	6.84	7.15	7.47	8.09	8.40	8.71
95	3 3/4	4.25	5.67	5.81	6.02	6.38	6.73	7.09	7.44	7.80	8.15	8.51	9.21	9.57	9.92
102	4	4.90	6.54	6.70	6.95	7.35	7.76	8.17	8.58	8.99	9.40	9.81	10.62	11.03	11.44
108	4 1/4	5.50	7.33	7.51	7.79	8.24	8.70	9.16	9.62	10.08	10.54	10.99	11.91	12.37	12.83
114	4 1/2	6.12	8.17	8.37	8.68	9.19	9.70	10.21	10.72	11.23	11.74	12.25	13.27	13.78	14.29
121	4 3/4	6.90	9.20	9.43	9.77	10.35	10.92	11.50	12.07	12.65	13.22	13.80	14.95	15.52	16.10
127	5	7.60	10.13	10.39	10.77	11.40	12.03	12.67	13.30	13.93	14.57	15.20	16.47	17.10	17.73
133	5 1/4	8.34	11.11	11.39	11.81	12.50	13.20	13.89	14.59	15.28	15.98	16.67	18.06	18.76	19.45
140	5 1/2	9.24	12.32	12.62	13.08	13.85	14.62	15.39	16.16	16.93	17.70	18.47	20.01	20.78	21.55
146	5 3/4	10.04	13.39	13.73	14.23	15.07	15.90	16.74	17.58	18.42	19.25	20.09	21.76	22.60	23.44
152	6	10.89	14.52	14.88	15.42	16.33	17.24	18.15	19.05	19.96	20.87	21.78	23.59	24.50	25.40
159	6 1/4	11.91	15.88	16.28	16.88	17.87	18.86	19.86	20.85	21.84	22.83	23.83	25.81	26.81	27.80
165	6 1/2	12.83	17.11	17.53	18.18	19.24	20.31	21.38	22.45	23.52	24.59	25.66	27.80	28.87	29.94
172	6 3/4	13.94	18.59	19.05	19.75	20.91	22.07	23.24	24.40	25.56	26.72	27.88	30.21	31.37	32.53
178	7	14.93	19.91	20.41	21.15	22.40	23.64	24.88	26.13	27.37	28.62	29.86	32.35	33.59	34.84
187	7 1/4	16.48	21.97	22.52	23.34	24.72	26.09	27.46	28.84	30.21	31.58	32.96	35.70	37.08	38.45
200	7 1/2	18.85	25.13	25.76	26.70	28.27	29.85	31.42	32.99	34.56	36.13	37.70	40.84	42.41	43.98
203	8	19.42	25.89	26.54	27.51	29.13	30.75	32.37	33.98	35.60	37.22	38.84	42.08	43.69	45.31
216	8 1/2	21.99	29.31	30.05	31.15	32.98	34.81	36.64	38.48	40.31	42.14	43.97	47.64	49.47	51.30
229	9	24.71	32.95	33.77	35.01	37.07	39.13	41.19	43.25	45.31	47.37	49.42	53.54	55.60	57.66
251	9 1/2	29.69	39.58	40.57	42.06	44.53	47.01	49.48	51.95	54.43	56.90	59.38	64.33	66.80	69.27
254	10	30.40	40.54	41.55	43.07	45.60	48.14	50.67	53.20	55.74	58.27	60.80	65.87	68.41	70.94
270	10 1/2	34.35	45.80	46.95	48.67	51.53	54.39	57.26	60.12	62.98	65.84	68.71	74.43	77.29	80.16
279	11	36.68	48.91	50.13	51.97	55.02	58.08	61.14	64.19	67.25	70.31	73.36	79.48	82.53	85.59
311	12 1/4	45.58	60.77	62.29	64.57	68.37	72.17	75.96	79.76	83.56	87.36	91.16	98.75	102.55	106.35
381	15	68.41	91.21	93.49	96.91	102.61	108.31	114.01	119.71	125.41	131.11	136.81	148.21	153.91	159.61
445	17 1/2	93.32	124.42	127.53	132.20	139.98	147.75	155.53	163.30	171.08	178.86	186.63	202.19	209.96	217.74

Load and spacing

Explosive load (kg/m)

$$d_{ec} = \frac{D_h^2}{121.93}$$

d_{ec} = expl. Load

D_h = blasthole diameter

Spacing (cm) is $Sp = 10D_h$

In imperial units:

$$d_{ec} = \frac{D_h^2}{28}$$

Seismic Effect

$$D_s = 2.2\frac{d}{\sqrt{W}}$$

- D_s = scaled distance

In imperial units:

$$D_s = \frac{d}{\sqrt{W}}$$

• d = distance to nearest structure • W = maximum charge weight per delay • 50 or more is safe	

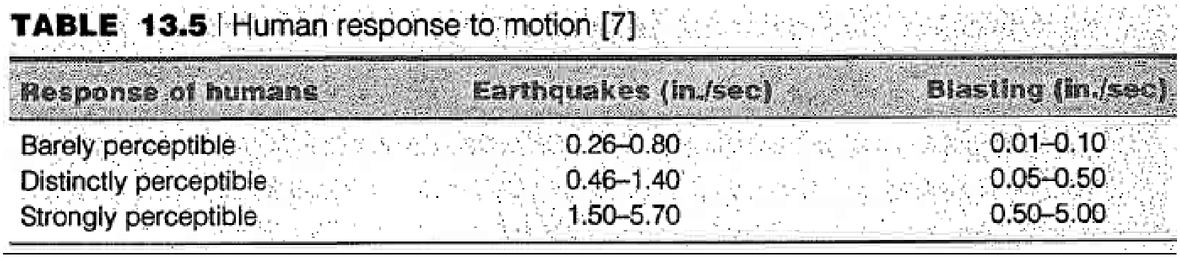


TABLE 13.5 | Human response to motion [7]

Response of humans	Earthquakes (in./sec)	Blasting (in./sec)
Barely perceptible	0.26–0.80	0.01–0.10
Distinctly perceptible	0.46–1.40	0.05–0.50
Strongly perceptible	1.50–5.70	0.50–5.00

Loading & Hauling

Haul cycle time = fixed time + variable time
Total resistance = Grade resistance + Rolling resistance; Unit = resistance factor (kg/t)
Grade resistance = vehicle weight x sine of incline angle
Grade resistance factor (kg/t) = 10 x Grade (%)
Grade resistance (kg) = Weight (kg) x Grade (%) = Weight (t) x Grade resistance factor (kg/t)
Effective grade (%) = Grade (%) + Rolling Resistance factor (kg/t) / 10
Derating factor (%) = (altitude(m)-915)/102
Maximum pull = Traction coeff. X weight
Avg. speed = max speed x avg. speed factor (Table 4-3)

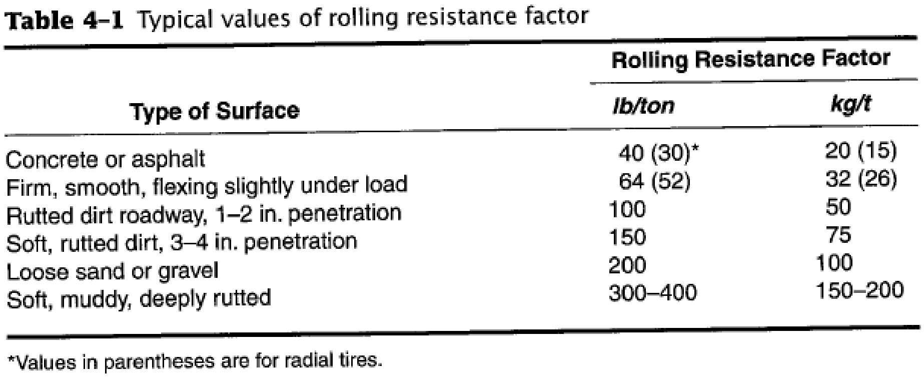


Table 4–1 Typical values of rolling resistance factor

Type of Surface	Rolling Resistance Factor	
	lb/ton	kg/t
Concrete or asphalt	40 (30)*	20 (15)
Firm, smooth, flexing slightly under load	64 (52)	32 (26)
Rutted dirt roadway, 1–2 in. penetration	100	50
Soft, rutted dirt, 3–4 in. penetration	150	75
Loose sand or gravel	200	100
Soft, muddy, deeply rutted	300–400	150–200

*Values in parentheses are for radial tires.

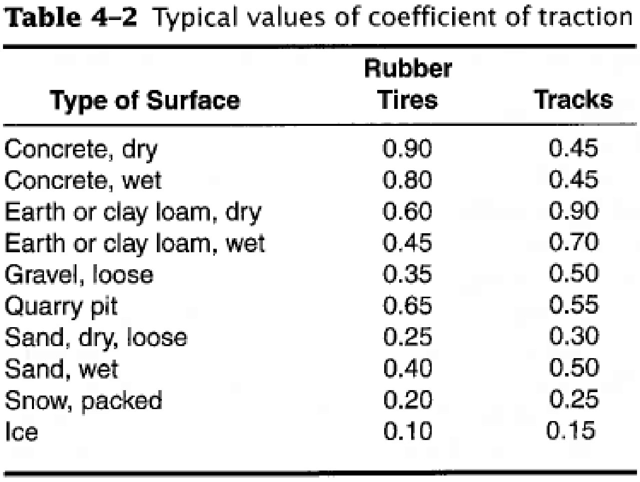
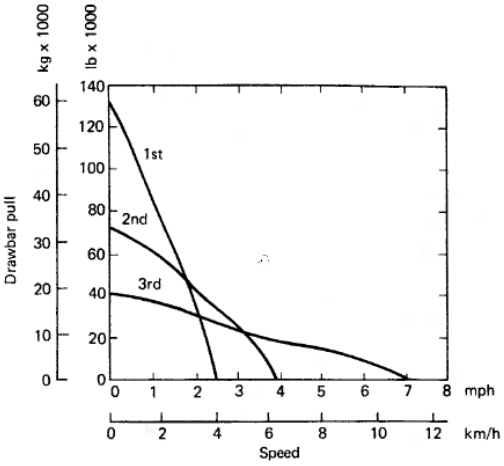


Table 4–2 Typical values of coefficient of traction

Type of Surface	Rubber Tires	Tracks
Concrete, dry	0.90	0.45
Concrete, wet	0.80	0.45
Earth or clay loam, dry	0.60	0.90
Earth or clay loam, wet	0.45	0.70
Gravel, loose	0.35	0.50
Quarry pit	0.65	0.55
Sand, dry, loose	0.25	0.30
Sand, wet	0.40	0.50
Snow, packed	0.20	0.25
Ice	0.10	0.15

Performance & Retarder Curves



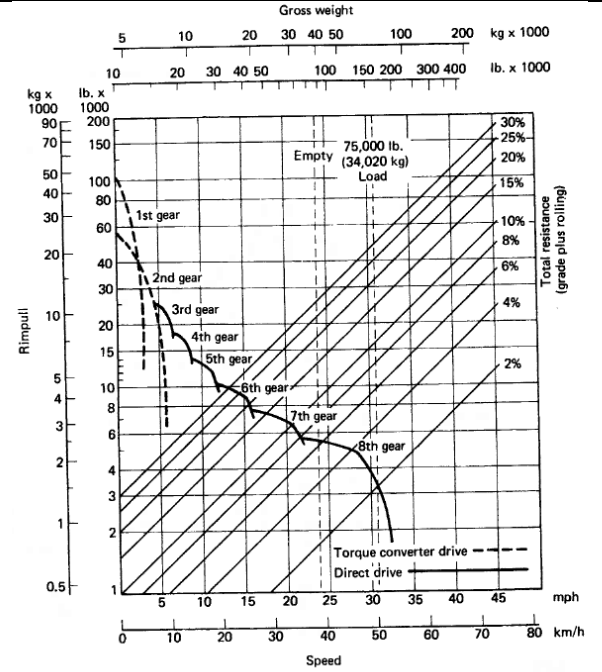
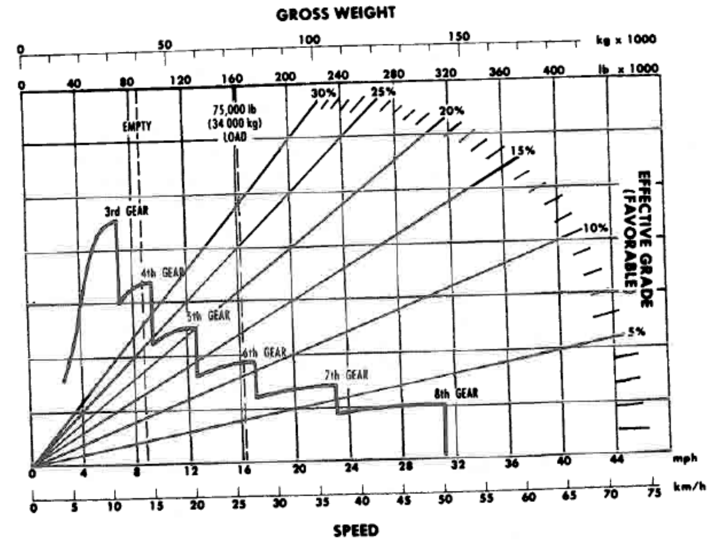
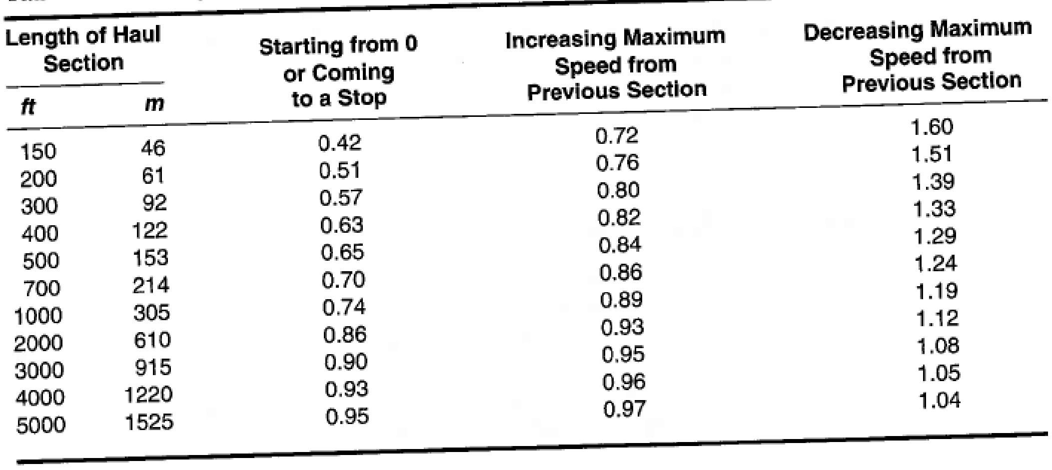
Performance Curves	Retarder Curves
	

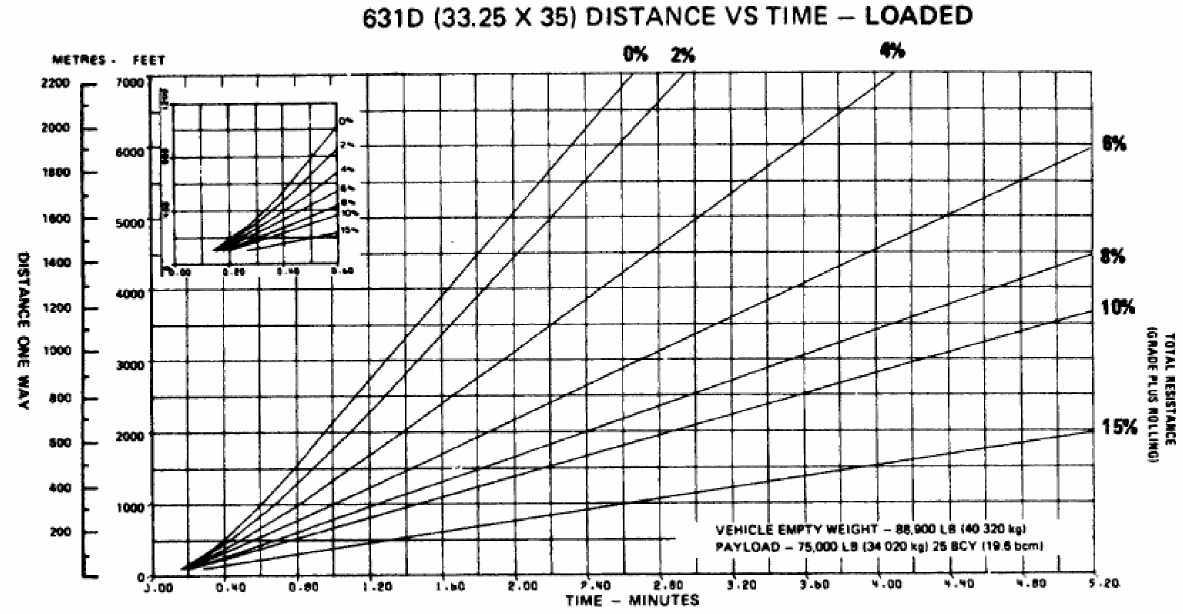
Table 4-3 Average speed factors



Length of Haul Section		Starting from 0 or Coming to a Stop	Increasing Maximum Speed from Previous Section	Decreasing Maximum Speed from Previous Section
ft	*m*			
150	46	0.42	0.72	1.60
200	61	0.51	0.76	1.51
300	92	0.57	0.80	1.39
400	122	0.63	0.82	1.33
500	153	0.65	0.84	1.29
700	214	0.70	0.86	1.24
1000	305	0.74	0.89	1.19
2000	610	0.86	0.93	1.12
3000	915	0.90	0.95	1.08
4000	1220	0.93	0.96	1.05
5000	1525	0.95	0.97	1.04

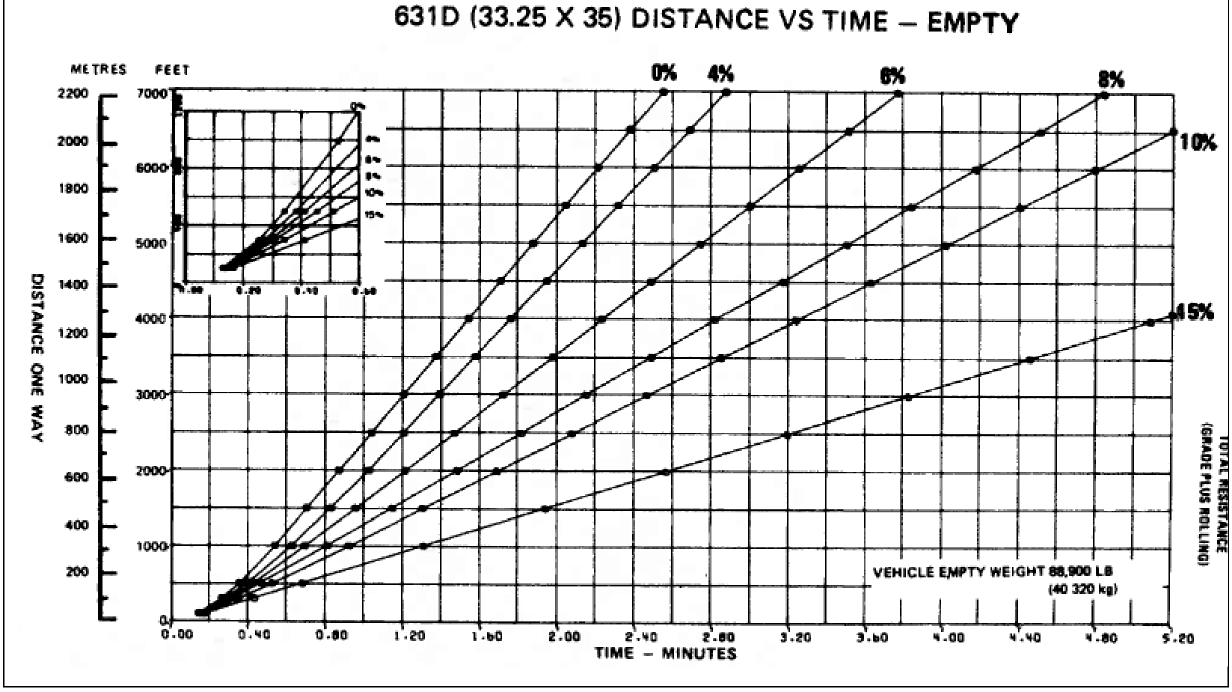
Estimating Travel Time

adj. time = time x (1+derating factor)



631D (33.25 X 35) DISTANCE VS TIME – LOADED

- Don't use for negative grade

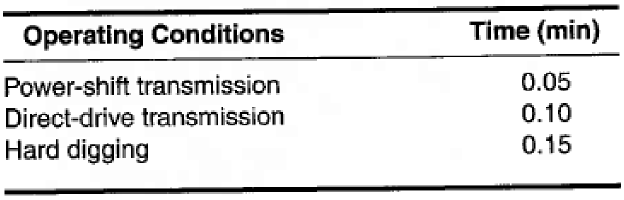


631D (33.25 X 35) DISTANCE VS TIME – EMPTY

Dozer Production

Blade load (LCM) = 0.375 x H (m) x W (m) x L (m)

Table 4–4 Typical dozer fixed cycle times



Operating Conditions	Time (min)
Power-shift transmission	0.05
Direct-drive transmission	0.10
Hard digging	0.15

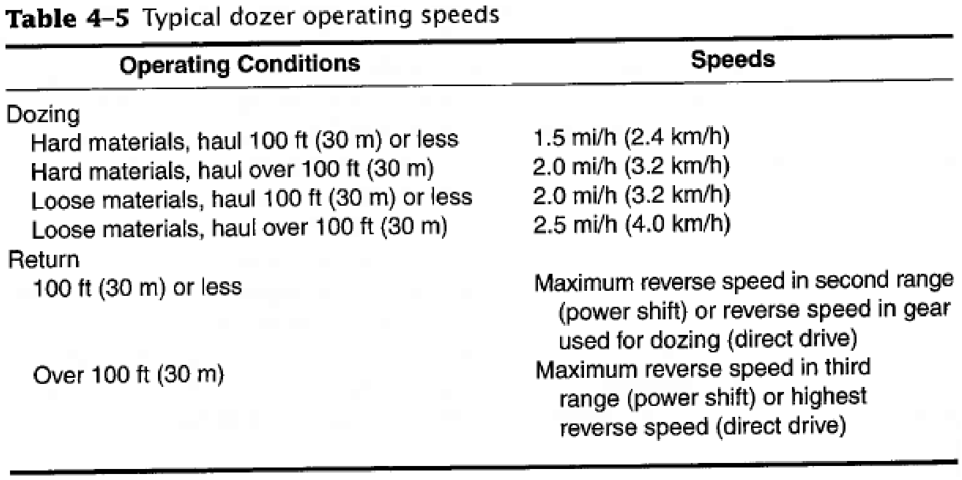


Table 4–5 Typical dozer operating speeds

Operating Conditions	Speeds
Dozing	
Hard materials, haul 100 ft (30 m) or less	1.5 mi/h (2.4 km/h)
Hard materials, haul over 100 ft (30 m)	2.0 mi/h (3.2 km/h)
Loose materials, haul 100 ft (30 m) or less	2.0 mi/h (3.2 km/h)
Loose materials, haul over 100 ft (30 m)	2.5 mi/h (4.0 km/h)
Return	
100 ft (30 m) or less	Maximum reverse speed in second range (power shift) or reverse speed in gear used for dozing (direct drive)
Over 100 ft (30 m)	Maximum reverse speed in third range (power shift) or highest reverse speed (direct drive)

<u>Loader Production</u>

Production = avg. bucket load x cycles/hour

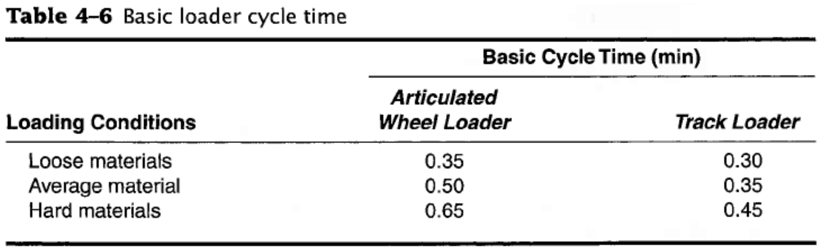
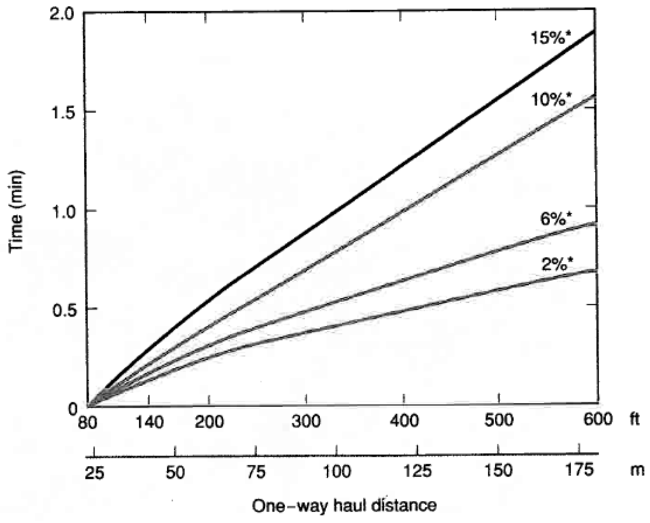


Table 4–6 Basic loader cycle time

	Basic Cycle Time (min)	
Loading Conditions	***Articulated Wheel Loader***	***Track Loader***
Loose materials	0.35	0.30
Average material	0.50	0.35
Hard materials	0.65	0.45



*Effective grade

Scraper Production

Table 4–7 Scraper fixed time (min)

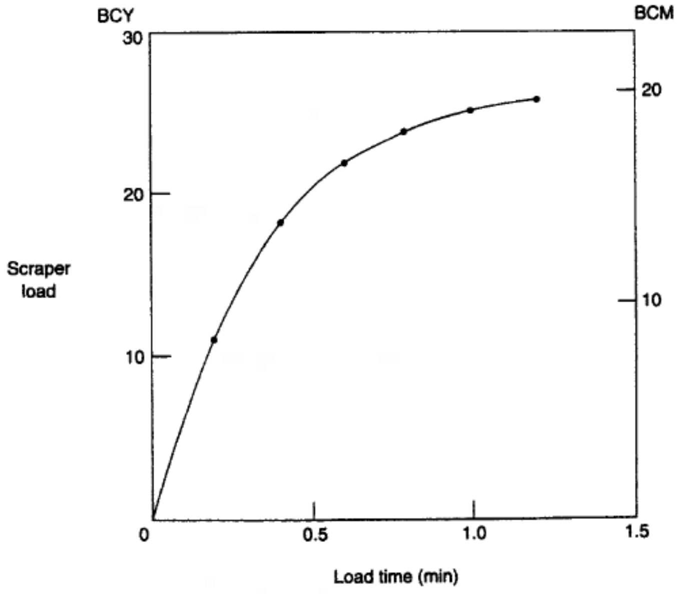
	Spot Time	
Conditions	***Single Pusher***	***Tandem Pusher***
Favorable	0.2	0.1
Average	0.3	0.2
Unfavorable	0.5	0.5

	Load Time				
Conditions	***Single Pusher***	***Tandem Pusher***	***Elevating Scraper***	***Auger***	***Push-Pull****
Favorable	0.5	0.4	0.8	0.7	0.7
Average	0.6	0.5	1.0	0.9	1.0
Unfavorable	1.0	0.9	1.5	1.3	1.4

	Maneuver and Dump Time	
Conditions	***Single Engine***	***Twin Engine***
Favorable	0.3	0.3
Average	0.7	0.6
Unfavorable	1.0	0.9

*Per pair of scrapers.

Push Loading



Calculating Required Pushers

Scrapers/pusher = Scraper cycle time / Pusher cycle time
Pushers=Scrapers/ (Scrapers/pusher)
If pushers less than required
Production = (Pushers/Req. Pushers) x Scrapers x Scr. Production

Table 4–8 Typical pusher cycle time (min)

Loading Method	Single Pusher	Tandem Pusher
Back-track	1.5	1.4
Chain or shuttle	1.0	0.9

Trucks
Load time = haul capacity / Loader production
Load time = Bucket loads x excavator cycle time

Haulers = haul unit cycle time/load time
*If less haul units available: Expected production = (Haulers / Req. Haulers) * Max Production*

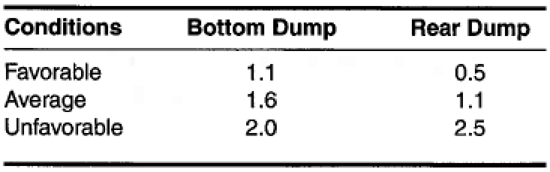


Table 4–9 Spot, maneuver, and dump time for trucks and wagons (min)

Conditions	Bottom Dump	Rear Dump
Favorable	1.1	0.5
Average	1.6	1.1
Unfavorable	2.0	2.5

Bidding

Lump sum job

b = amount of bid = cost plus markup
c = actual cost of work
Potential profit = b – c
EP = expected profit = p*(b-c)
p = probability GC is low bidder with a bid equal to b

Business methods, organisational structures

Percentage of completion method
Percentage = project costs incurred during FY / total estimated contract cost + revised amounts

Income Statement
Gross Profit = Income – costs
Operating Profit = Gross Profit – expenses + other
Taxation = Corporation tax + Non-deductible items – tax losses carried forward
Retained earnings = Existing reserves + Profit after Tax
Earnings Per Share = Profit after Tax/Shares in issue

Balance Sheet
Assets = liabilities + net worth
Net Assets = Total Assets - Liabilities

Financial Ratios

Quick assets to current liabilities (quick ratio/acid test) $\frac{Cash\ and\ Debtors}{Current\ Liabilities}$

Current assets to current liabilities (current ratio) $\frac{Current\ Assets}{Current\ Liabilities}$

Total liabilities to net worth (debt to equity ratio) $\frac{Total\ Liabilities}{Shareholder\ Equity}$

Project income to net working capital, also project income to net worth

$$\frac{Turnover}{Net\ Current\ Assets}$$

$$\frac{Turnover}{Capital\ and\ Reserves}$$

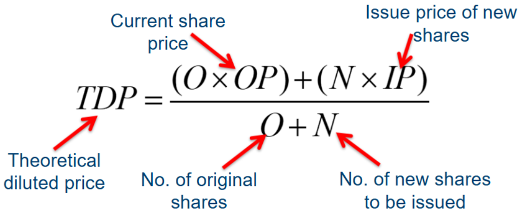
Fixed assets to net worth $\frac{Fixed\ Assets}{Capital\ and\ Reserves}$

Percent net project income (bef. taxes) $\frac{Operating\ Profit}{Turnover}$

Percent net project income (bef. taxes) to net worth $\frac{Profit\ before\ Tax}{Capital\ and\ Reserves}\%$

Percent net project income (bef. taxes) to total assets $\frac{Profit\ before\ Tax}{Total\ Assets}\%$

Value Dilution



$$TDP = \frac{(O \times OP) + (N \times IP)}{O + N}$$