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THE DIGGABILITY ASSESSMENT USING POWER CONSUMPTION OF ELECTRICAL POWER SHOVELS

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By

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ABSTRACT

THE DIGGABILITY ASSESSMENT USING POWER CONSUMPTION OF ELECTRICAL POWER SHOVELS

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In this thesis, the performance and power consumptions of electrical power shovels are evaluated to determine the excavation difficulty of coal measure rocks present at T.K.İ's (Turkish Coal Enterprises) surface coal mines.

A new measurement technique consisting of wattmeter and recorder system has been developed and utilized in this study.

The main A.C. motor of the electrical shovel is connected to the wattmeter - recorder system and power measurements are carried out simultaneously with the performance measurements.

Field measurements are carried out at 47 different locations. The collected data is analyzed and formations have been classified with respect to their excavation difficulty. The power measurement results are compared with the classical cycle time measurements, and it indicated that they are in good agreement with each other.

Key words: Wattmeter - recorder system, electric power shovel, performance measurements, excavation difficulty.

ÖZET

ELEKTRİKLİ EKSKAVATÖRLERİN GÜÇ TÜKETİMİNİ KULLANARAK KAZILABİLİRLİK TAYİNİ

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Bu tezde, Türkiye Kömür İşletmeleri'nin yerüstü kömür ocaklarında bulunan ana kömür kayaçlarının kazı zorluğunu belirlemek için elektrikli ekskavatörlerin performans ve güç tüketimleri değerlendirilmiştir.

Watmetre ve kaydedici sisteminden oluşan yeni bir ölçüm tekniği geliştirilmis ve bu çalışmada kullanılmıştır.

Elektrikli ekskavatörün ana A.C. motoru watmetre-kaydedici sistemine bağlanmış ve güç ölçümleri performans ölçümleriyle birlikte sürdürülmüştür.

Arazi ölçümleri 47 değişik lokasyonda sürdürülmüştür. Alınan veriler analiz edilmiş ve formasyonlar kazı zorluklarına göre sınıflandırılmıştır. Güç ölçümleri sonuçları klasik period ölçümleri ile karşılaştırılmış ve birbirleriyle iyi bir uyum içinde olduklarını göstermiştir.

Anahtar sözcükler: Watmetre- kaydedici sistemi,elektrikli elektrikli ekskavatör, performans ölçümleri, kazı zorluğu

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CHAPTER 1

INTRODUCTION

The prediction of the diggability of rock units is the most important concept in overburden removal operations. Digging conditions, type of excavating equipment, capacity and the operational conditions are the factors which affect the production of surface mine excavating equipments.

The performance measurements of the electrical power shovels are used as an indicator of digging difficulty of formations in the literature. The capacity differences of shovels is the most important and complex parameter to be considered during the classification of formations with respect to the performance measurements. There are limited studies on diggability classification of formations with respect to the power and energy consumptions of electrical shovels in the literature.

A new measurement system consisting of wattmeter and recorder developed by Middle East Tecnical University Rock Mechanics Research Group is utilized to measure the power and energy consumptions of electrical shovels during the overburden removal operations of different formations those in Turkish surface coal mines.

The aim of this thesis is to clasify the excavation condition of formations with respect to the performance parameters. Not only the clasical cycle time but also the power and energy consumption measurements are analyzed to determine the classifications of excavation condition.

The parameters considered in performance measurements are explained in chapter two. Development of power measuring set up is presented in chapter three. In chapter four, the performance measurements in the field are explained in detail. The results and analysis of performance measurements are presented in chapter five. In the last chapter, conclusions of this study and some recommendations are given for future studies.

CHAPTER 2

PERFORMANCE MEASUREMENTS OF ELECTRICAL POWER SHOVELS

2.1. Introduction

Classifications of diggability of formations in the litareture is a complex phenomena and mainly depends on the geotechnical parameters of the formations and can generally be measurable with cycle times for various dipper capacities of the excavators and the dipper fill factors of the excavators.

A brief information about the electric power shovel is given before the explanations of the effective parameters for the performance measurements on assesment of diggability.

2.2 Electrical Power Shovel

The electrical power shovels are designed to scoop the material from ground level where they are operated, the dipper moving vertically through the working face of the formation and to dump either to a spoil pile or into a haulage unit. Four operations are involved in this process, these being hoist, crowd, swing and propel.

Electric power shovels are used with trucks in stripping operations in open-pit mines. The productions of these machines change according to their size, model and digging difficulty of formations. The operational conditions such as truck availability, operator experience, bech height, floor condition also affect the production rate.

Terminology and Major shovel units which are lower frame, upper revolving frame and digging attachment are shown in Figure 1.

The general dimensions vary with the capacity of shovel. The general dimensions of a typical 10 yd^3 dipper capacity shovel are identified in Figure 2.

The operating specifications also vary with each model shovel but they can be constant for different dipper capacities. The operating specifications of the shovel and the four operating motions involved in the cycle process of the shovel, these being hoist, crowd, swing and propel are shown in Figure 3. The four operating motions of hoist, crowd, swing and propel are individually motored and functioned independently. Especially crowd and propel motions can not be operated at the same time.

2.3. Performance Measurements of Electrical Shovels on Assesment of Diggability

The performances of excavators with respect to digging

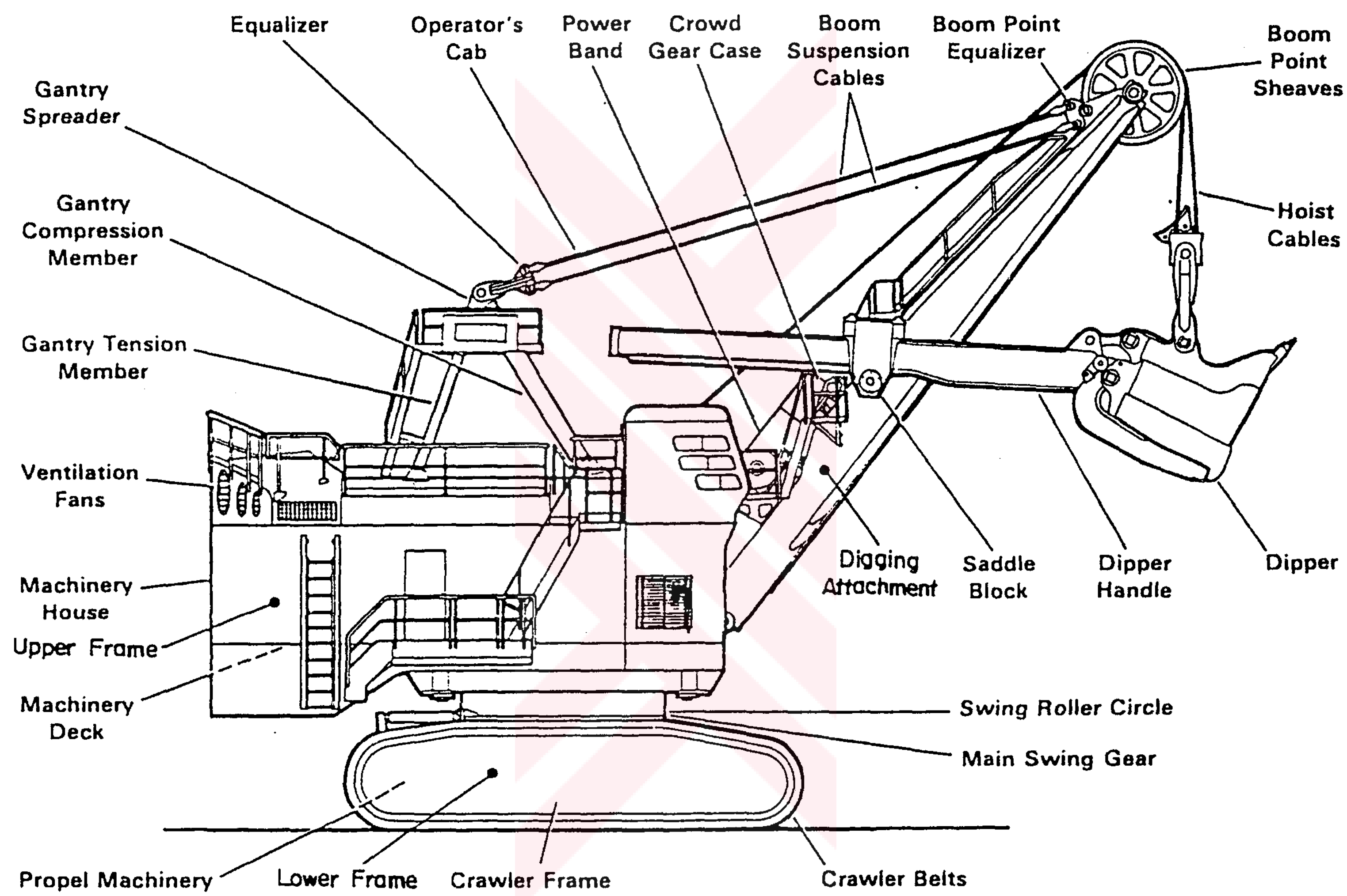
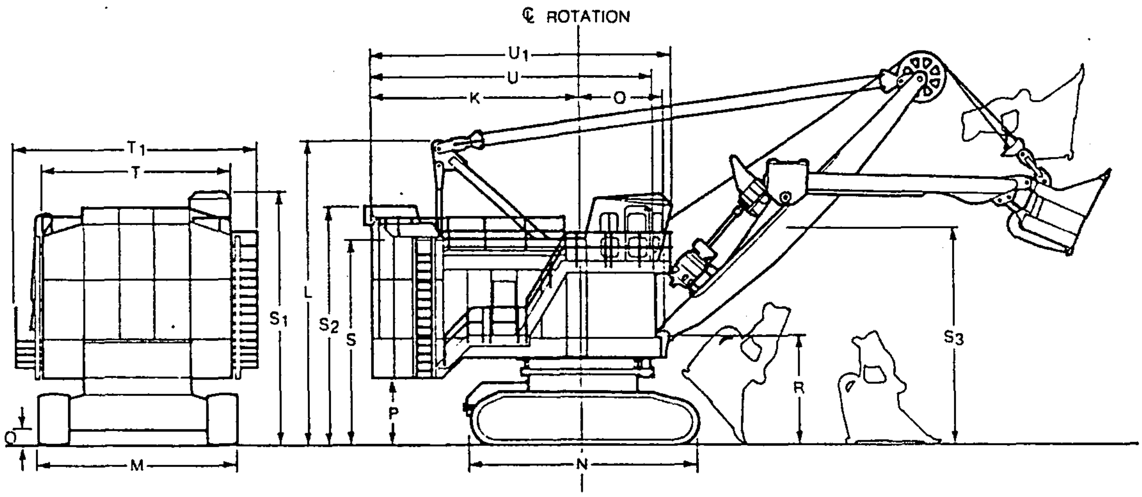
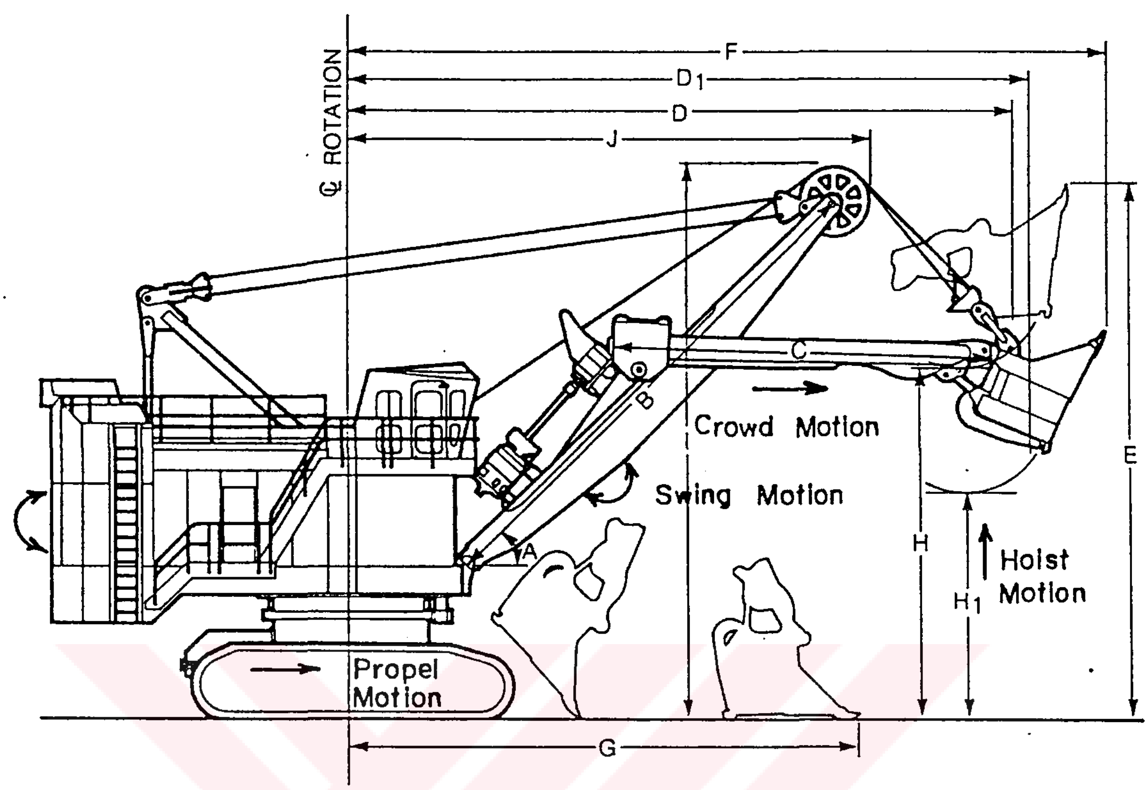


Figure 1. Terminology and major units of a shovel



K	Radius of Rear End	23 ft. 0 in.	7.01 m
L	Max. Height Over Gantry	33 ft. 2 in.	10.11 m
M	Overall Width of Crawlers (42" Shoes)	22 ft. 0 in.	6.71 m
N	Overall Length of Crawlers	25 ft. 0 in.	7.62 m
O	Ground Clearance	1 ft. 9 in.	0.53 m
P	Height — Ground to Bottom of Counterweight	7 ft. 5 in.	2.26 m
Q	Center of Rotation to Boom Foot Pin	9 ft. 4 in.	2.84 m
R	Height — Ground to Boom Foot Pin	11 ft. 11 in.	3.63 m
S	Height — Ground to Top of Main Cab	22 ft. 0 in.	6.70 m
S_1	Height — Ground to Top of Operator's Compartment	27 ft. 6 in.	8.38 m
S_2	Height — Ground to Top of Rear Canopy Section	25 ft. 8 in.	7.82 m
S_3	Height — Ground to Operator's Eye Level	24 ft. 3 in.	7.39 m
T	Width of Cab	21 ft. 0 in.	6.40 m
T_1	Width of Cab and Stair Platform	26 ft. 5 in.	8.05 m
U	Overall Length of Main Cab	32 ft. 0 in.	9.75 m
U_1	Overall Length of Cab and Operator Compartment	34 ft. 0 in.	10.36 m

Figure 2. General dimensions of the electrical shovel with a 10 yd^3 dipper capacity



A	Boom Angle	45°	45°
	Dipper Capacity (Nominal)	12 cu. yd.	9 cu. m
	Dipper Capacity (Range)	10-25 cu. yd.	7.5-19.1 cu. m
B	Boom Length	40 ft. 0 in.	12.19 m
C	Effective Dipper Handle Length	27 ft. 0 in.	8.23 m
D	Dumping Radius at Max. Lift	52 ft. 0 in.	15.85 m
D_1	Dumping Radius (Max.)	53 ft. 0 in.	16.15 m
E	Height of Cut (Max.)	42 ft. 6 in.	12.95 m
F	Digging Radius (Max.)	58 ft. 6 in.	17.83 m
G	Floor Level Radius	39 ft. 0 in.	11.89 m
H	Dumping Height (Max.) — Door Open	27 ft. 0 in.	8.23 m
H_1	Dumping Height at Max. Radius — Door Open	19 ft. 0 in.	5.79 m
I	Clearance Height of Boom Point Sheave	43 ft. 0 in.	13.11 m
J	Clearance Radius of Boom Point Sheave	40 ft. 3 in.	12.27 m

Figure 3. Working ranges and operating motions of the electrical shovel

difficulty of formations are mainly measured by the cycle times, dipper fill factors and hourly outputs.

The work cycle is a complete process of the excavator to fill its dipper from ground level where it is operated to the vertical direction of the working face and dump its load into the haulage unit and return for the next cycle with swing motion. Therefore,the cycle of the excavator is composed of four segments as follows:

1. Load dipper
2. Swing loaded to the haulage unit
3. Dump dipper into the haulage unit
4. Swing empty for the next cycle

The average cycle time is dependent on machine size, small machines can cycle faster than large machines, and digging difficulty. As the formation gets harder to dig, it takes longer to fill the dipper.

The proposed average cycle times of different electrical shovel manufacturing componies as a function of digging difficulty are given in Table 1.

The dipper fill factor is a percentage expression of the amount of the dipper's capacity that is utilized. When the dipper is filled to

Table 1. The Average Cycle Times of Electrical Shovels as a Function of Digging Difficulty (P and H., Marion., 1980)

Classifications of Digging / Dipper Capacity (yd^3)	Easy	Easy - Moderate	Moderate	Moderate- Moderately Difficult	Moderately Difficult	Moderately Difficult- Difficult	Difficult
	t_s (sec)	t_s (sec)	t_s (sec)	t_s (sec)	t_s (sec)	t_s (sec)	t_s (sec)
4.5	20.43	22.56	24.69	26.55	28.40	30.02	31.63
10	23.04	25.17	27.30	29.16	31.01	32.63	34.24
10.5	23.24	25.37	27.50	29.36	31.21	32.83	34.44
15	24.70	26.83	28.96	30.82	32.67	34.29	35.90
17	25.17	27.30	29.43	31.29	33.14	34.76	36.37
20	25.67	27.80	29.93	31.79	33.64	35.26	36.87
25	25.96	28.09	30.22	32.08	33.93	35.55	37.16

less than 100%, by the percent of available capacity not utilized. On occasion, material may be heaped to excess of dipper struck measure, meaning the fill factor is 100% plus some fractions.

It is difficult to excavate and fill the dipper as the formations tend to be hard. The literature classifications of digging by means of dipper fill factors are given in Table 2.

Table 2. Classifications of Digging by Means of Dipper Fill Factors (P and H)

Clasifications of Digging	Dipper Fill Factor (FF)
Easy	FF ⩾ 0.95
Moderate	0.90 ⩾ FF < 0.95
Moderately Difficult	0.80 ⩾ FF < 0.90
Difficult	FF < 0.80

The output of the shovel is directly propotional with the dipper capacity and the dipper fill factor and inversly propotional with the cycle time.

Hourly capacities (m^3/hr) of the shovels with the dipper capacity ranging from 4.5 to 25 yd^3 are calculated for ease of digging of formations and at the same time to see the combination effects of the cycle times and dipper fill factors on classifications of digging.

The cycle times and dipper fill factors for classifications of digging given in Table 1 and Table 2 are used to find the literature hourly capacities of different dipper capacities for different digging conditions. The following formula is used for four classifications of digging:

$$\text{Hourly Capacity } (m^3/hr) = \frac{3600 * FF * C_d}{ts}$$

where: ts: Cycle time (sec)

FF: Dipper fill factor

Cd: Dipper capacity, m^3

3600: This number divided by cycle time in seconds gives the number of cycles per hour that the shovel will take.

Litareture hourly capacities of electrical shovels as a measure of digging difficulty are given in Table 3.

Table 3. Hourly Capacities of Electrical Shovels as a Measure of Digging Difficulty (P and H., Marion., 1980)

Classifications of Digging / Dipper Capacity (yd^3)	Easy	Easy - Moderate	Moderate	Moderate-Moderately Difficult	Moderately Difficult	Moderately Difficult-Difficult	Difficult
	HC (m^3/hr)	HC (m^3/hr)	HC (m^3/hr)	HC (m^3/hr)	HC (m^3/hr)	HC (m^3/hr)	HC (m^3/hr)
4.5	591.1	521.6	464.1	414.1	370.7	330.1	293.7
10	1164.8	1038.9	932.6	837.8	754.5	674.9	602.9
10.5	1212.5	1082.3	972.2	873.7	787.1	704.3	629.4
15	1629.8	1461.9	1318.8	1189.0	1074.2	963.3	862.6
17	1812.6	1628.3	1470.7	1327.2	1200.2	1077.0	964.9
20	2091.0	1881.2	1701.4	1536.9	1391.0	1249.0	1119.8
25	2584.5	2327.3	2106.3	1903.8	1723.9	1548.6	1388.9

CHAPTER 3

DEVELOPMENT OF POWER MEASURING SET UP

3.1. Introduction

The energy consumption of shovels during excavation is another approach of analysing the digging difficulty of formations. However this may not always be a good indication to show the digging difficultly. Some type of electrical shovels work with an active-passive energy consumption system i.e. their main drive A.C. motor can also work as a generator espicially during the reverse motion of the hoist. For this type of electric shovels, it is not easy to evaluate the energy consumptions in each phase of a cycle. In such a conditions, power measurements are considered the best way.

Shirley Williamson, Cameron McKenzie and Harry O'Loughlin (1983) recorded the signals of d.c. motors of electrical shovels to provide informations on digging conditions. They recorded the crowd motor signals in terms of voltage and current to explain the digging conditions. The total horse power of the crowd motor is 130 (0.097 MW) and the total horse power of the hoist motor is 600 (0.448 MW) for a 10 yd^3 dipper capacity electric shovel. The crowd action pushes the lip of the dipper into the formation at the start of digging and then the hoist force is exerted until the end of digging. The effective power is the hoist motor power during loading the dipper as it is seen from the value of the total horse power of the hoist motor.

The main drive A.C. motor of the shovel provides all mechanical power for crowd, hoist, swing and propel motions. The simplified working principle of the electrical power shovel is given in Figure 4.

In this work, the wattmeter and recorder system developed by Middle East Tecnical University Rock Mechanics Research Group is utilized to record the main drive A.C. motor power with respect to time.

3.2. Wattmeter and Recorder System

The wattmeter is used to measure the power of any required system continuously. The measured power of the system can easily be followed by the indicator of wattmeter at any time during the measurement. The wattmeter also outputs D.C. Volt according to the power of the system continuously. The block diagram given in Figure 5 . illustrates the working system of the wattmeter.

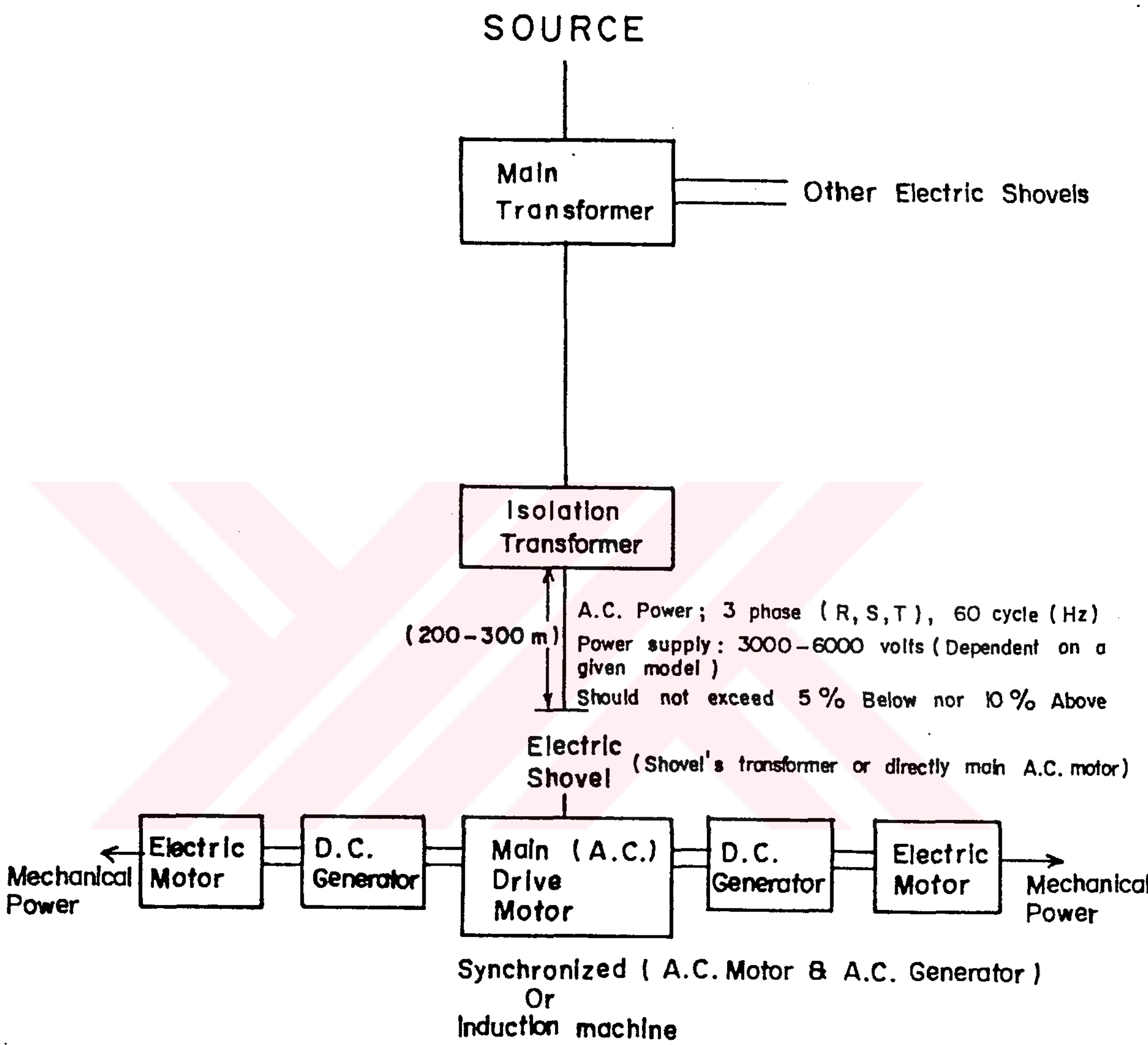


Figure 4. Simplified working system of an electrical power shovel

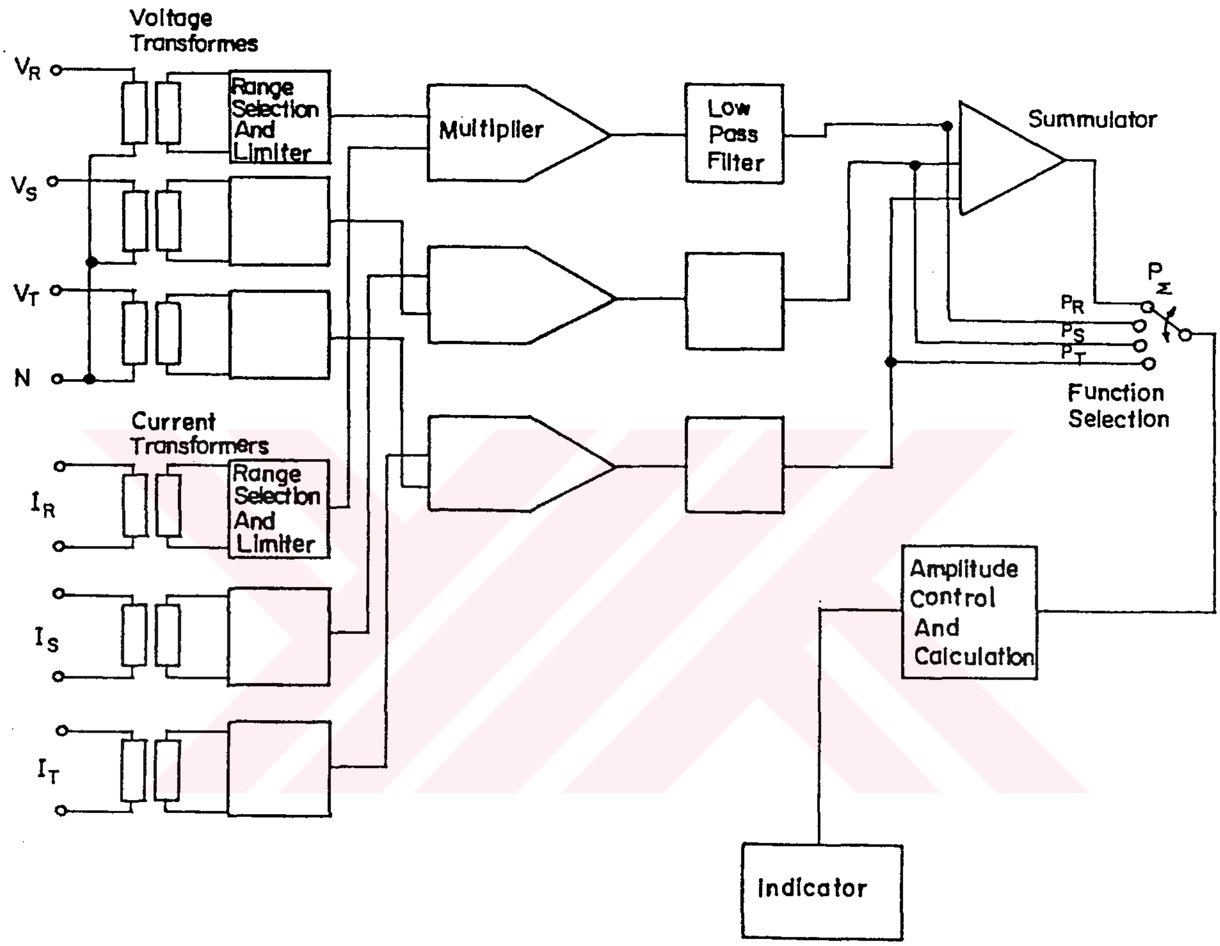


Figure 5. Working system of the wattmeter

The size of the wattmeter is 40*30*15 cm., and the weight is approximately 7 kg and the power supply is 220 Volt. The back and front views of the wattmeter are shown in Figure 6.

A dual-channel Yokogawa Hokushin Electric Model 3021 strip chart recorder is utilized as readout device in the monitoring system. The recorder is just used to record the output D.C. Volt of the wattmeter as a function of the power measured with respect to time continuously. The Volt range and the velocity of the record are selected from the strip chart recorder.

The connections of the wattmeter and recorder to a given transformer system is shown in Figure 7. The power of the system can be calculated at any time during the measurement as follows:

W (Watt)= Wattmeter Indicator Number$_*$ Wattmeter

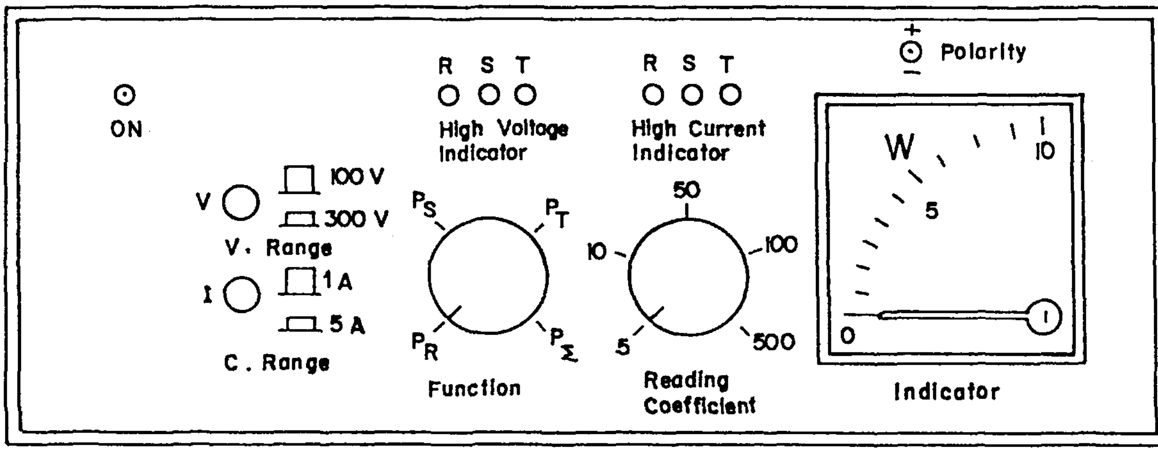
Reading Coefficient$_*$a$_*$b

where ; a: Voltage Transformer Turns Ratio

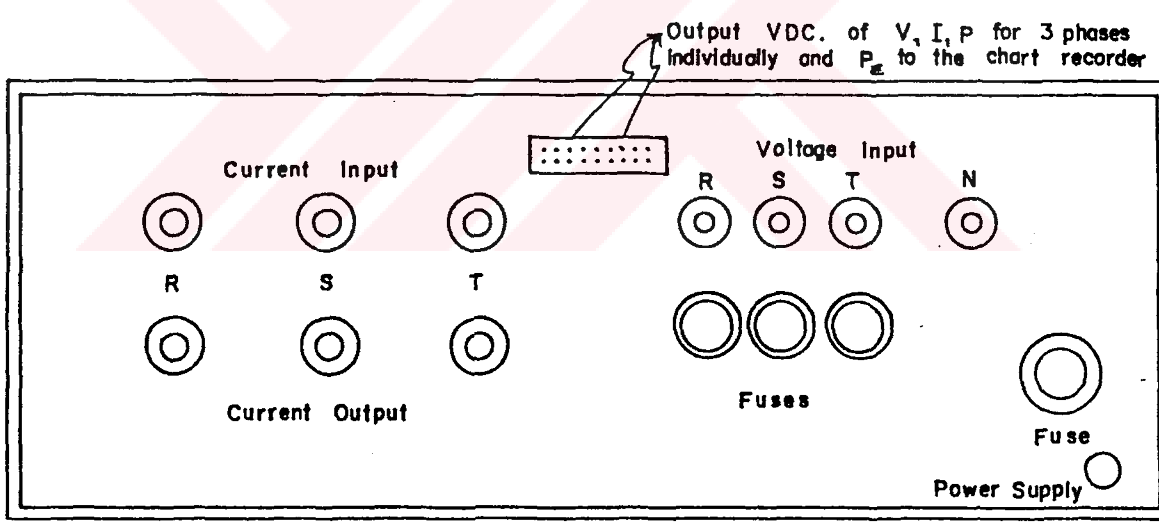
b: Current Transformer Turns Ratio

The analog D.C. Volt outputs of the wattmeter related with the power of the measured system which can be recorded separately with chart recorder are as follows:

1. Voltage of the R phase (V_R)
2. Current of the R phase (I_R)



Front view



Back view

Figure 6. Front and back views of the wattmeter

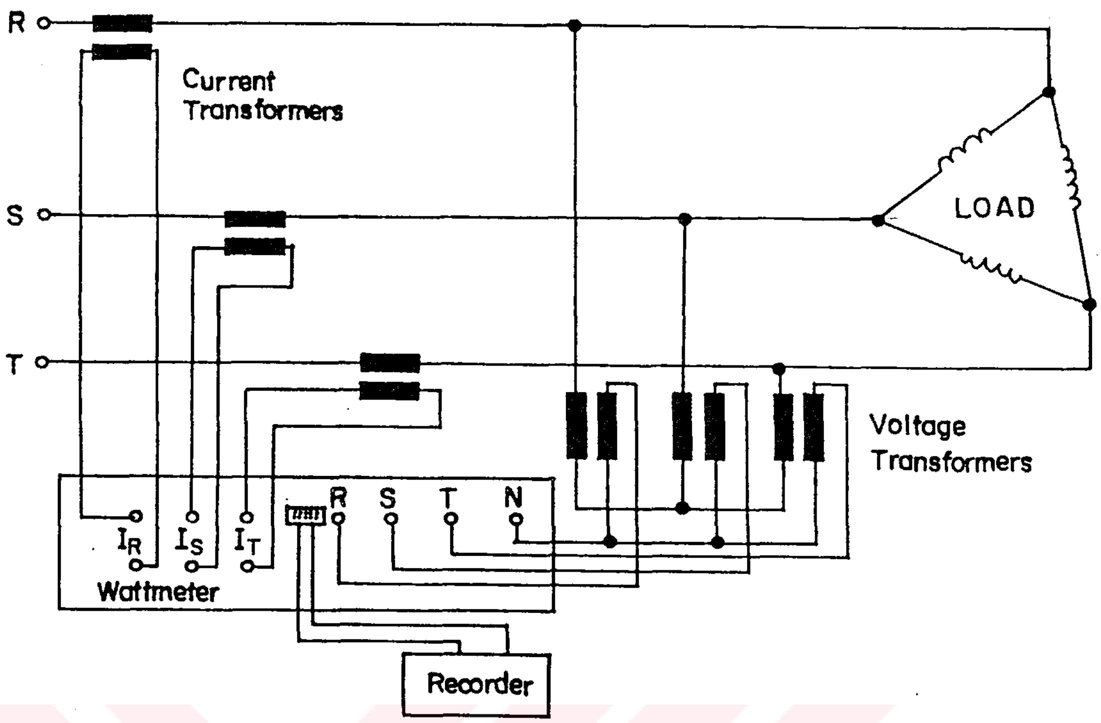


Figure 7. Connections of the wattmeter and recorder to a given transformer system

3. Power of the R phase (P_R)

4. Voltage of the S phase (V_S)

5. Current of the S phase (I_S)

6. Power of the S phase (P_S)

7. Voltage of the T phase (V_T)

8. Current of the T phase (T_T)

9. Power of the T phase (P_T)

10. Total power of there phases (P_Σ)

The wattmeter is designed to give 2.5 D.C. Volt analog output for each P_R, P_S and P_T phases at the nominal power of the selected voltage and current ranges. Therefore, the total analog output of the wattmeter P_Σ is 7.5 D.C. Volt at the desired conditions. At the 100 V/1A ranges the 2.5 D.C. Volt output corresponds to 100 W nominal power for a single phase and at the same range the 7.5 D.C. Volt output of P_Σ corresponds to 300W nominal power. At the 300W/5A ranges the 2.5 D.C. Volt output corresponds to 1500W nominal power for one phase and 7.5 D.C. Volt output of P_Σ corresponds 4500W nominal power.

The analog D.C. Volt output of the wattmeter related to the power of the system is calibrated by using the graph given in Figure 8.

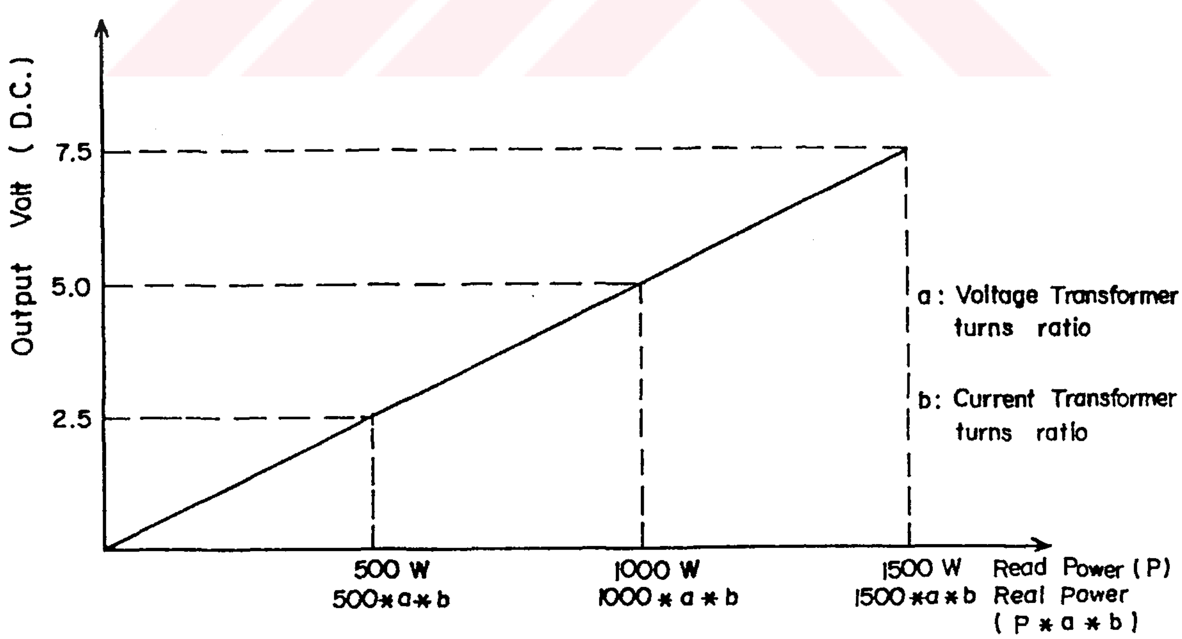


Figure 8. Calibration graph of the wattmeter – recorder measurement

The D.C. Volt recorded by chart recorder corresponds the power of the measured system at any time. A typical record of wattmeter- recorder system is presented in Figure 9.

The consumed total power of the excavator at any time on the recorder is calculated as follows:

First R(D.C.Volt) is determined on the recorder.

$$R\ (\text{D.C.Volt}) = \text{Recorder Volt Range (D.C. Volt)} * \frac{X\ (\text{mm})}{250\ (\text{mm})}$$

where; 250mm is the whole length of the chart

X is the measured length at that time in mm.

Secondly, the nominal power of the wattmeter for P_{Σ} is calculated.

$$N\ (\text{Watt}) = \text{Wattmeter V. Range} * \text{Wattmeter C. Range} * 3 * a * b$$

where: a and b are used to find the real power of the measured system

a: Voltage Transformer Turn Ratio

b: Current Transformer Turn Ratio

Then, total power of the system at that time is:

$$P_{\Sigma}\ (\text{Watt}) = \frac{R\ (\text{D.C.Volt}) * N\ (\text{Watt})}{7.5\ (\text{D.C. Volt})}$$

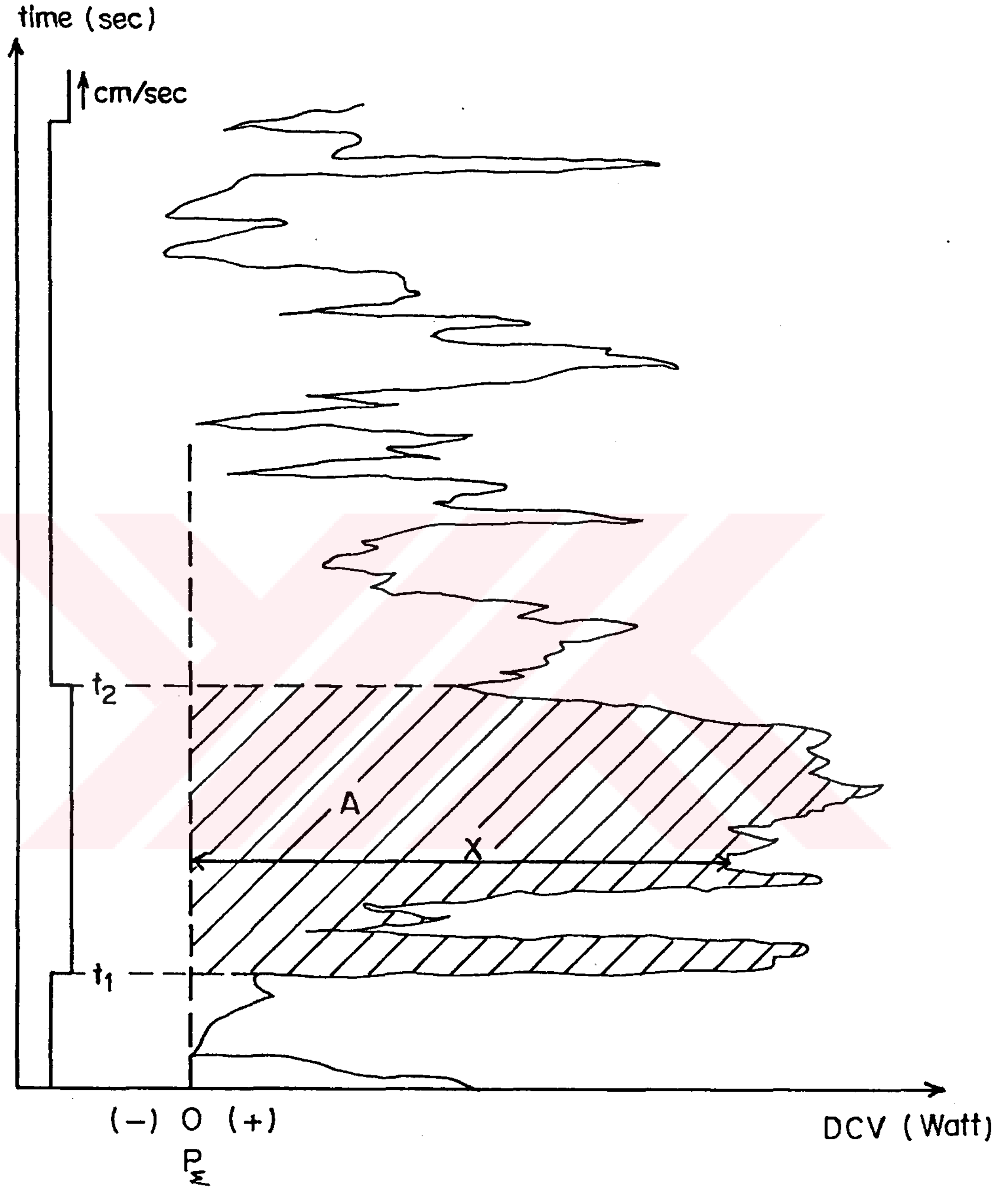


Figure 9. A typical record of wattmeter and recorder system

Remote control pen of the chart recorder which draws straight line at the left side of the chart is used to indicate the required time intervals. This line is also shown in Figure 9.

The energy of the measured system for a given time interval is calculated as follows:

$$\int_{t_1}^{t_2} Wdt = \text{Watt.sec.}$$

It is difficult to integrate the above equation without analog-digital system. Then the prodedure outlined below is used for practical purposes:

$$\frac{A\ (cm^2)}{X\ (cm/Watt) * \frac{y\ (cm/min)}{60}} = \text{Watt.sec.}$$

where; A is the area under the record with the given time interval (cm_2)

y is the recorder velocity (cm/min)

x is the recording ranges (cm/Watt)

3.3. Measurement Procedure With Wattmeter-Recorder System

The following procedure is applied to measure the power of the required system continuously with wattmeter-recorder system.

1. Connect the given system to the wattmeter.

2. Connect the wattmeter to the chart recorder.

3. Note the voltage and current turns ratios of the given system.

4. Supply 220Volt for wattmeter and recorder.

5. Select the voltage range and current range from the wattmeter. If the high voltage indicators light on, select another range (300V) and if the high current indicators light on, select the other range (5 Amp.). Note the measurement ranges of the wattmeter.

6. Control the polarity of three phase from the function button of the wattmeter. All three phases, P_R , P_S and P_T must be in the same direction to measure P_Σ correctly.If they are not in the same direction, control the connections of current input and output.

7. Select the function and set the correct reading coefficient from the wattmeter. Set the largest value of the reading coefficient which is 500 at the beginning of the measurement and decrease the reading coefficient according to the indicator of the wattmeter.

8. Set the suitable volt range and velocity from the chart recorder.

9. Indicate the zero line on the chart.

10. Note the volt range, velocity of the recorder and output of the wattmeter which can be P_R , P_S , P_T or P_Σ .

CHAPTER 4

FIELD STUDIES

4.1. Introduction

Performance measurements of electrical power shovels are carried at TKİ's (Turkish Coal Enterprises) surface coal mines for the determination of excavation conditions. Table 4 summarizes the mines and the formations where the measurements are carried out.

4.2. Performance Measurements

Overburden removal operations of eight different models of electrical power shovels with the dipper capacity ranging from 4.5 to 25 yd^3 are observed for different excavation conditions. At each location the following parameters are recorded carefully to indicate the excavation conditions:

1. Cycle time (sec)
2. Dipper fill factor
3. Digging power (MWatt)

The performence information form given in Table 5 is

Table 4. T.K.İ.'s Surface Coal Mines Where the Performance Measurements are Carried Out.

ENTERPRISE	LOCATION	PANEL	FORMATION
E.L.İ	Merkez	Kısrakdere-Doğu Kısrakdere-Batı Işıklar A Pano Işıklar DE Pano Elmalı Sarıkaya	Marl Marl Marl Marl Marl Marl
	Deniş	Çamtarla	Marl
G.L.İ	Tunçbilek	Beke Ömerler 36. Pano Kuşpınar	Marl Marl Marl Marl,Limestone
	Seyitömer	S-20 S-19 S-18	Marl Marl Marl
G.E.L.İ	Yatağan	Eskihisar	Marl
	Tınaz-Bağyaka	Tınaz	Conglomerate,Marl Limestone
	Milas	İkizköy Sekköy	Marl, Limestone Marl
S.K.L.İ	Kalburçayırı		Marl, Clayish Marl Limestone

Table 5. M.E.T.U. Mining Engineering Department Excavator Performance Information Form

Date:......
Code No:....

Mine, Region & Panel:...

Formation:..

Degree of Weathering:..

Blasted or Not:...

Working Conditions:

Bench Height:...

Condition of the Shovel Floor:.................................

The Distance Between the Face & the Shovel:.....

Double or Single Side Loading:.................................

Operator Experience (total working time of the operator):...

Electric Shovel Dipper Capacity, Model and Age:..

Voltage Transformers of the Shovel Turns Ratio:........................

Current Transformers of the Shovel Turns Ratio:........................

Number of Current Transformers:..

Wattmeter Volt Range:...

Wattmeter Current Range:..

Wattmeter Reading Coefficient:...

Recorder Volt Range:...

Recorder Velocity Range:...

completed at the beginning of the each measurement. A brief description of the formation, operational conditions and power measurement variables of the electrical power shovel are noted.

The cycle time measurements are repeated for 40-60 cycles at each location. It was sufficient, since there is no significant changes in the average of measurements as the duration of measurements increased. Cycle time measurements are maintained continuously during the whole measurement period, including down time and break times. The dipper fill factor and swing angle are also noted continuously. The typical cycle time data sheet is given in Table 6.

The cycle time and wattmeter-recorder system outputs are taken simultaneously. Wattmeter and recorder system is connected to the secondary ends of the isolated transformer of the shovel or directly to the shovel's transformer which is inside the shovel to measure the total power of the main drive A.C. motor of the electric shovel with respect to time continuously. Some models of electric shovels have no transformer inside the shovel. In those cases it was not posible to see shovel's different steps of cycle if the wattmeter and recorder system is connected to the isolated transformer of the electric shovel. Two hand-held radios are used for comminication in those situations to indicate the shovel motions. The dipper fill factor and the qualitative describtion of the formation such as easy, moderate or difficult are also noted continuously during the performance measurement.

Table 6. The Cycle Time Data Sheet

Date:..............
Code No..........

*Down Time	Beginning of the cycle *Beginning of the down time	End of dipper filling * End of down time	Dipper fill factor	Swing Angle (Degree)	Explanations
	0.00	0.10	0.8	80	
	0.25	0.34	0.9	90	
	0.55	1.07	0.8	100	
*	1.75	1.20	-	-	Propel
	1.40	1.50	0.9	90	
	2.05	2.11	0.7	80	
	2.30	2.39	1.0	110	
	2.58	3.08	0.8	100	
*	3.32	4.50	-	-	Wait for truck or others
	4.50	5.01	1.0	70	
	5.17	.	.	.	
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Each measurement is numbered to compare them with each other and analyse easily. The total number of measurements carried out in the field was 47 and the code numbers of those measurements are given on the performance results tables. The results of the measurements will be analysed in the following chapter.

CHAPTER 5

ANALYSIS AND DISCUSSION OF RESULTS

5.1. Evaluation of the Performance Measurements

The cycle time measurement data is directly calculated by a simple basic program prepared by Rock Mechanics Research Group. The following parameters are derived and the results of each location presented in Table 7. These are:

1. Total measurement time (sec)
   It is the total measurement time including all cycle times, down times and break times.

2. Total cycle time (sec)
   It is the summation of all cycle times obtained during the measurement.

3. Total dipper fill time (sec)
   It is the summation of all dipper fill times obtained during the measurement.

4. Number of cycle times

5. Average cycle time (sec)=Total cycle time/No. of cycle

6. Average dipper fill time (sec)=Total dipper fill time/No. of cycle

Table 7. The Results of Cycle Time Measurements

Code No.	Region and Panel	Formation Desciription and Operational Conditions	Shovels: Dipper Capacity (yd^3) Model Age	Total Measurement Time (sec)	Total Cycle Time (sec)	Total Dipper Fill Time (sec)	Number of Cycles	Average Cycle Time (sec)	Average Dipper Fill Time (sec)	Average Dipper Fill Factor	Total Output (m^3)	Actual Hourly Capacity (m^3/hr)	Hourly Capacity Without Waiting (m^3/hr)
1	Soma Kısrakdere-Doğu	Fresh to slightly weathered marl and top soil Double side loading Operator Experience: 12 years Blasted	20 yd^3 Marion 191M-II 1.5 years	3642	3224	982	115	28.04	8.54	0.66	1157.6	1144.3	1292.6
2	Soma Isıklar-DE Pano	Fresh to slightly weathered marl Double side loading Operator: 1 month Blasted	20 yd^3 Marion 191M-II 1 year	1973	1525	368	55	27.73	6.69	0.49	415.9	758.9	981.9
3	Soma Kısrakdere-Batı	Highly weathered marl Single side loading (~90°) Operator: 2 years Balsted	17 yd^3 Marion 191M-I 1 year	1638	1030	274	34	30.29	8.06	0.99	438.0	962.7	1531.0
4	Soma Kısrakdere-Batı	Slightly to moderately weathered marl Single side loading (~90°) Operator: 8 years Blasted	4.5 yd^3 Machine Export 17 years	1342	860	236	31	27.74	7.61	0.70	75.00	201.2	313.9

Table 7. Continued

Code No.	Region and Panel	Formation Description and Operational Conditions	Shovels: Dipper Capacity (yd^3) Model Age	Total Measurement Time (sec)	Total Cycle Time (sec)	Total Dipper Fill Time (sec)	Number of Cycles	Average Cycle Time (sec)	Average Dipper Fill Time (sec)	Average Dipper Fill Factor	Total Output (m^3)	Actual Hourly Capacity (m^3/hr)	Hourly Capacity Without Waiting (m^3/hr)
5	Soma Işıklar A-Pano	Moderately to highly weathered tuff, marl Double side loading Operator: 1 year	20 yd^3 Marion 191M 1.5 years	1562	1215	376	36	33.75	10.44	0.73	403.7	930.4	1196.2
6	Soma Elmalı	Fresh to slightly weathered marl Single side loading (40-50°) Operator: 20 years Blasted	10.5 yd^3 EKG-8i	1499	1268	512	43	29.49	11.91	0.42	144.5	347.1	410.3
7	Soma Sarıkaya	Moderately to highly weathered marl, tuff and top soil Double side loading Operator: 20 years	15 yd^3 P and H 2100BL 1 year	2352	1685	473	57	29.56	8.30	0.75	490.9	751.3	1048.8
8	Deniş Çamtarla	Fresh to slightly weathered marl and some shear zones Double side loading Blasted	20 yd^3 Marion 191M-II	1516	1153	347	42	27.45	8.26	0.43	278.3	660.9	869.0

Table 7. Continued

Code No.	Region and Panel	Formation Description and Operational Conditions	Shovels: Dipper Capacity (yd^3) Model Age	Total Measurement Time (sec)	Total Cycle Time (sec)	Total Dipper Fill Time (sec)	Number of Cycles	Average Cycle Time (sec)	Average Dipper Fill Time (sec)	Average Dipper Fill Factor	Total Output (m^3)	Actual Hourly Capacity (m^3/hr)	Hourly Capacity Without Waiting (m^3/hr)
9	Denis Çamtarla	Fresh to slightly weathered marl and some shear zones Double side loading Blasted	10 yd^3 P and H 1900 AL	2055	1407	500	50	28.14	10.00	0.91	346.4	606.8	886.2
10	Tunçbilek Beke	Fresh to slightly weathered marl and top soil Double side loading Operator: 12 year Blasted	20 yd^3 P and H 2300 XP 0.5 year	3607	2331	704	76	30.67	9.26	0.92	1064.1	1062.1	1643.4
11	Tunçbilek Beke	Fresh marl Operator: 2 years Blasted	10 yd^3 P and H 1900 15 years	1145	554	144	24	23.08	6.00	1.00	184.4	579.7	1198.0
12	Tunçbilek Beke	Fresh marl Double side loading Operator: 12 years Blasted	17 yd^3 Marion 191-M 1 year	3296	2462	836	98	25.12	8.53	0.93	1180.4	1289.3	1726.0

Table 7. Continued

Code No.	Region and Panel	Formation Description and Operational Conditions	Shovels: Dipper Capacity (yd^3) Model Age	Total Measurement Time (sec)	Total Cycle Time (sec)	Total Dipper Fill Time (sec)	Number of Cycles	Average Cycle Time (sec)	Average Dipper Fill Time (sec)	Average Dipper Fill Factor	Total Output (m^3)	Actual Hourly Capacity (m^3/hr)	Hourly Capacity Without Waiting (m^3/hr)
13	Tunçbilek Ömerler	Moderately weathered marl and top soil Double side loading Operator: 12 years	20 yd^3 P and H 2300 XP 1 year	3525	2693	643	83	32.45	7.75	1.06	1347.9	1376.6	1801.9
14	Tunçbilek Ömerler	Moderately weathered marl,some shear zones and top soil Double side loading Operator: 10 years	10 yd^3 P and H 1900 19 years	1662	1314	436	55	23.89	7.93	1.00	421.3	912.5	1154.2
15	Tunçbilek Ömerler	Highly to completely weathered marl Double side loading Operator: 10 years	10 yd^3 P and H 1900 19 years	641	497	159	21	23.67	7.57	1.03	165.2	927.5	1196.3
16	Tunçbilek 36 Pano	Completely weathered marl (At the bottom of the bench ~70cm. thick.fresh marl) Double side loading Operator: 10 years	20 yd^3 P and H 2300 XP 0.5 year	1714	1596	513	61	26.16	8.41	1.04	974.9	2047.6	2198.9

Table 7. Continued

Code No.	Region and Panel	Formation Description and Operational Conditions	Shovels: Dipper Capacity (yd^3) Model Age	Total Measurement Time (sec)	Total Cycle Time (sec)	Total Dipper Fill Time (sec)	Number of Cycles	Average Cycle Time (sec)	Average Dipper Fill Time (sec)	Average Dipper Fill Factor	Total Output (m^3)	Actual Hourly Capacity (m^3/hr)	Hourly Capacity Without Waiting (m^3/hr)
17	Tunçbilek 36 Pano	Fresh to slightly weathered marl Single side loading Operator: 10 years Blasted	10 yd^3 P and H 1900 AL 1 year	2024	1293	469	50	25.86	9.38	0.88	336.4	598.4	936.7
18	Tunçbilek Kuşpınar	Completely weathered marl (At the bottom of the bench ~1m thickness fresh marl) (Shovel is far from the face) Single side loading Operator: 5 years	10.5 yd^3 EKG- 8i 12 years	1444	1394	478	57	24.46	8.38	0.75	344.4	858.7	889.4
19	Tunçbilek Kuşpınar	Slightly to moderately weathered marl Double side loading Operator: 6 years	10 yd^3 P and H 1900 10 years	2273	1679	650	63	26.65	10.32	0.68	329.5	521.9	706.6
20	Seyitömer S-20	Clayish fresh marl and tuff Operator: 11 years Blasted	10 yd^3 P and H 1900 AL 1 year	2372	1978	600	80	24.72	7.50	0.86	526.8	799.5	958.8

Table 7. Continued

Code No.	Region and Panel	Formation Description and Operational Conditions	Shovels: Dipper Capacity (yd^3) Model Age	Total Measurement Time (sec)	Total Cycle Time (sec)	Total Dipper Fill Time (sec)	Number of Cycles	Average Cycle Time (sec)	Average Dipper Fill Time (sec)	Average Dipper Fill Factor	Total Output (m^3)	Actual Hourly Capacity (m^3/hr)	Hourly Capacity Without Waiting (m3/hr)
25	Seyitömer S-19	Fresh to moderately weathered marl Single side loading Operator: 5 years Blasted	10 yd^3 P and H 1900 AL 3 months	1556	1280	421	47	27.23	8.96	1.07	386.9	895.1	1088.1
26	Seyitömer S-18	Moderately to highly weathered clayish marl Operator: 18 years	10 yd^3 P and H 1900 AL 1 year	2407	1629	440	69	23.61	6.38	0.88	464.9	695.3	1027.4
27	Seyitömer S-18	Highly weathered clayish marl	10 yd^3 P and H 1900 AL 10 years	1039	926	277	37	25.03	7.49	1.05	296.7	1027.9	1153.3
28	Yatağan Eskihisar	Highly weathered marl and soil Double side loading Operator: 4 years	15 yd^3 P and H 2100 BL 4 years	1536	1318	424	46	28.65	9.22	1.05	555.1	1301.0	1516.2

Table 7. Continued

Code No.	Region and Panel	Formation Desciription and Operational Conditions	Shovels: Dipper Capacity (yd^3) Model Age	Total Measurement Time (sec)	Total Cycle Time (sec)	Total Dipper Fill Time (sec)	Number of Cycles	Average Cycle Time (sec)	Average Dipper Fill Time (sec)	Average Dipper Fill Factor	Total Output (m^3)	Actual Hourly Capacity (m^3/hr)	Hourly Capacity Without Waiting (m^3/hr)
29	Yatağan Eskihisar	Slightly to moderately weathered marl Double side loading Operator: 4 years Blasted	$15\ yd^3$ P and H 2100 BL 4 years	515	428	135	16	26.75	8.44	1.09	200.1	1399.0	1683.4
30	Yatağan Eskihisar	Slightly to moderately weathered marl Double side loading Operator: 4 years	$15\ yd^3$ P and H 2100 BL 4 years	663	502	185	18	27.89	10.27	1.06	219.1	1189.5	1570.9
31	Yatağan Eskihisar	Highly weathered clayish marl and soil Double side loading Operator: 2 years	$10\ yd^3$ P and H 1900 AL 4 years	1830	1830	689	61	30.00	11.29	1.05	490.1	964.1	964.1
32	Yatağan Eskihisar	Moderately weathered marl Single side loading Operator: 2 years	$10\ yd^3$ P and H 1900 AL 4 years	548	428	168	15	28.53	11.20	1.07	122.3	803.7	1029.0

Table 7. Continued

Code No.	Region and Panel	Formation Desciription and Operational Conditions	Shovels: Dipper Capacity (yd^3) Model Age	Total Measurement Time (sec)	Total Cycle Time (sec)	Total Dipper Fill Time (sec)	Number of Cycles	Average Cycle Time (sec)	Average Dipper Fill Time (sec)	Average Dipper Fill Factor	Total Output (m^3)	Actual Hourly Capacity (m^3/hr)	Hourly Capacity Without Waiting (m3/hr)
33	Yatağan Eskihisar	Highly weathered clayish marl and soil Double side loading Operator: 1 year	15 yd^3 P and H 2100 BL 4 years	1934	1430	425	41	34.88	10.37	1.04	487.4	907.3	1227.1
34	Yatağan Eskihisar	Moderately to highly weathered marl and soil Single side loading Operator: 3.5 years	15 yd^3 P and H 2100 BL 4 years	1620	938	237	32	29.31	7.41	0.65	237.4	527.6	911.2
35	Tınaz	Slightly weathered clayish and sandy weakly cemented conglamerate	15 yd^3 P and H 2100 BL 1.5 years	2535	2414	1015	81	29.80	12.53	1.07	992.1	1408.9	1479.5
36	Tınaz	Slightly weathered clayish and sandy weakly cemented conglomerate Operator: 4.5 months	15 yd^3 P and H 2100 BL 1.5 years	1809	1713	745	48	35.69	15.52	1.17	646.9	1287.3	1359.4

Table 7. Continued

Code No.	Region and Panel	Formation Desciription and Operational Conditions	Shovels: Dipper Capacity (yd^3) Model Age	Total Measurement Time (sec)	Total Cycle Time (sec)	Total Dipper Fill Time (sec)	Number of Cycles	Average Cycle Time (sec)	Average Dipper Fill Time (sec)	Average Dipper Fill Factor	Total Output (m^3)	Actual Hourly Capacity (m^3/hr)	Hourly Capacity Without Waiting (m^3/hr)
37	Tınaz	Highly weathered limestone (Moderately weathered limestone at the bottom of the bench) Double side loading	15 yd^3 P and H 2100 BL 1.5 years	1995	1690	820	51	38.43	16.08	1.22	715.7	1291.4	1314.5
38	Tınaz	Moderately weathered clayish limestone and marl Double side loading	15 yd^3 P and H 2100 BL 1 year	3035	2575	1082	80	32.19	13.52	1.20	1097.6	1301.9	1534.5
39	Milas İkizköy	Moderately to highly weathered marl and limestone blocks Double side loading Operator: 1.5 years Blasted	15 yd^3 P and H 2100 BL 0.5 year	1588	1236	461	43	28.74	10.72	0.88	434.7	985.4	1266.0
40	Milas İkizköy	Fresh to slightly weathered marl Double side loading Blasted	10 yd^3 P and H 1900 AL	1800	1325	487	53	25.00	9.19	0.97	393.8	787.5	1069.9

Table 7. Continued

Code No.	Region and Panel	Formation Description and Operational Conditions	Shovels: Dipper Capacity (yd^3) Model Age	Total Measurement Time (sec)	Total Cycle Time (sec)	Total Dipper Fill Time (sec)	Number of Cycles	Average Cycle Time (sec)	Average Dipper Fill Time (sec)	Average Dipper Fill Factor	Total Output (m^3)	Actual Hourly Capacity (m^3/hr)	Hourly Capacity Without Waiting (m^3/hr)
41	Milas İkizköy	Moderately weathered marl, limestone and soil Double side loading Blasted	15 yd^3 P and H 2100 BL	2127	1728	590	59	29.29	10.00	1.00	677.8	1147.2	1412.1
43	Milas Sekköy	Weak coal and soil Operator: 2 years	15 yd^3 P and H 2100 BL 1 month	1380	982	293	37	26.54	7.92	1.08	458.8	1196.8	1681.8
44	Kangal Kalburçayırı	Fresh to slightly weathered clayish marl Single side loading Operator: 2 years	25 yd^3 Marion 201 M 4 months	2026	752	241	20	37.60	12.05	0.79	300.1	533.4	1436.7
45	Kangal Kalburçayırı	Highly weathered limestone and soil (Fresh limestone at the bottom of the bench) Single side loading Operator: 2 years Blasted	25 yd^3 Marion 201 M 3.5 months	1785	1425	452	41	34.76	11.02	0.78	613.6	1237.5	1550.1

Table 7. Continued

Code No.	Region and Panel	Formation Description and Operational Conditions	Shovels: Dipper Capacity (yd^3) Model Age	Total Measurement Time (sec)	Total Cycle Time (sec)	Total Dipper Fill Time (sec)	Number of Cycles	Average Cycle Time (sec)	Average Dipper Fill Time (sec)	Average Dipper Fill Factor	Total Output (m^3)	Actual Hourly Capacity (m^3/hr)	Hourly Capacity Without Waiting (m^3/hr)
46	Kangal Kalburçayırı	Slightly to moderately weathered limestone and soil Double side loading Operator: 2 years Blasted	10 yd^3 P and H 1900 AL 4 months	2760	2026	643	72	28.14	8.93	0.96	526.0	686.1	934.7
47	Kangal Kalburçayırı	Slightly to moderately weathered limestone Double side loading Operator: 2 year Blasted	20 yd^3 Marion 191M-II 2 months	1801	865	242	26	33.27	9.31	0.77	305.8	611.3	1272.9

7. Average dipper fill factor=Total dipper fill factor/No. of cycle

8. Total output (m^3)= Total dipper fill factor*Dipper capacity

9. Actual Hourly Capacity (m^3/hr)= Total output*3600/Total measurement time

10. Hourly Capacity Without Waiting (m^3/hr)= Total output*3600/Total cycle time

$$= \frac{3600}{\text{Average cycle time}} * \text{Average Dipper Fill Factor} * \text{Dipper Capacity}$$

The calculation sequence of the main drive A.C motor power of the electric shovels at any time is explained in detail in Chapter 3. The developed basic program in accordance with the procedure outlined above is utilized for the calculation of provided data. The following parameters are calculated and given in Table 8. These are:

1. Mean of Average Digging Power (MWatt)

   The average digging powers correspond to all subsequent cycles are taken from the recorder. Then the summation of average digging powers are divided by the number of cycle to find the mean of average digging power for each measurement.

Table 8. The Results of Power Measurements

CODE NO	Region & Panel	Dipper Capacity (yd^3)	*(Digging) Mean of Average Digging Power (MW)	*(Digging) Maximum Digging Power (MW)	*(Digging) Average of Maximum Digging Power (MW)	*(Digging) Average Digging Energy Consumption (MW.sec)	(Loose Material) Mean of Average Digging Power (MW)	(Loose Material) Maximum Digging Power (MW)	(Loose Material) Average of Maximum Digging Power (MW)	(Loose Material) Average Digging Energy Consumption (MW.sec)	(Empty Digging Mation) Average Power (MW)	(Empty Digging Motion) Maximum Power (MW)
1	Soma/Kısrak-dere- Dogu	20	0.982	1.555	1.377	8.267	-	-	-	-	-	-
2	Soma/Işıklar DE Pano	20	0.911	1.447	1.287	6.300	-	-	-	-	-	-
3	Soma/Kısrak-dere -Batı	17	0.800	1.296	1.115	6.529	-	-	-	-	-	-
4	Soma/Kısrak-dere- Batı	4.5	0.250	0.393	0.370	1.968	-	-	-	-	-	-
5	Soma/Işıklar A Pano	20	0.850	1.243	1.145	8.329	-	-	-	-	-	-
6	Soma/Elmalı	10.5	0.539	1.017	0.876	6.159	-	-	-	-	-	-
7	Soma/Sarı-kaya	15	0.872	1.416	0.311	7.385	-	-	-	-	-	-
8	Deniş/Çam-tarla	20	0.923	1.566	1.362	7.617	0.916	1.361	1.242	4.637	0.333	0.432

Table 8. Continued

CODE NO	Region & Panel	Dipper Capacity (yd^3)	*(Digging) Mean of Average Digging Power (MW)	*(Digging) Maximum Digging Power (MW)	*(Digging) Average of Maximum Digging Power (MW)	*(Digging) Average Digging Energy Consumption (MW.sec)	(Loose Material) Mean of Average Digging Power (MW)	(Loose Material) Maximum Digging Power (MW)	(Loose Material) Average of Maximum Digging Power (MW)	(Loose Material) Average Digging Energy Consumption (MW.sec)	(Empty Digging Mation) Average Power (MW)	(Empty Digging Motion) Maximum Power (MW)
9	Deniş/Çam-tarla	10	0.955	1.282	1.183	10.086	0.811	1.080	1.032	7.041	0.299	0.324
10	Tunçbilek / Beke	20	1.105	1.786	1.670	7.735	-	-	-	-	-	-
11	Tunçbilek / Beke	10	1.157	1.987	1.805	6.188	-	-	-	-	-	-
12	Tunçbilek / Beke	17	0.843	1.194	1.130	4.726	-	-	-	-	-	-
13	Tunçbilek / Ömerler	20	1.492	2.218	2.029	8.987	1.175	1.814	1.757	8.813	-	-
14	Tunçbilek / Ömerler	10	1.799	2.153	2.143	14.244	-	-	-	-	0.878	1.930
15	Tunçbilek / Ömerler	10	1.823	2.174	2.155	16.178	-	-	-	-	0.878	1.930
16	Tunçbilek / 36. Pano	20	1.519	2.203	2.073	12.757	-	-	-	-	0.616	1.080

Table 8. Continued

CODE NO	Region & Panel	Dipper Capacity (yd^3)	*(Digging) Mean of Average Digging Power (MW)	*(Digging) Maximum Digging Power (MW)	*(Digging) Average of Maximum Digging Power (MW)	*(Digging) Average Digging Energy Consumption (MW.sec)	(Loose Material) Mean of Average Digging Power (MW)	(Loose Material) Maximum Digging Power (MW)	(Loose Material) Average of Maximum Digging Power (MW)	(Loose Material) Average Digging Energy Consumption (MW.sec)	(Empty Digging Mation) Average Power (MW)	(Empty Digging Motion) Maximum Power (MW)
17	Tunçbilek / 36. Pano	10	0.811	1.253	1.117	8.527	0.738	1.102	1.091	5.508	0.276	0.367
18	Tunçbilek / Kuşpınar	10.5	0.869	1.622	1.346	7.311	-	-	-	-	0.602	1.140
19	Tunçbilek / Kuspınar	10	0.699	1.022	1.022	8.720	0.594	0.927	0.927	4.206	0.321	0.523
20	Seyitömer / S-20	10	0.508	0.744	0.686	4.774	0.474	0.684	0.684	3.070	0.234	0.456
21	Seyitömer / S-20	10	0.821	1.227	1.181	6.558	0.714	1.123	1.039	4.451	-	-
22	Seyitömer / S-20	10	0.830	1.234	1.173	7.848	0.734	1.094	1.030	4.266	0.237	0.394
23	Seyitömer / S-20	10	0.774	1.247	1.235	7.600	0.741	1.195	1.159	5.522	0.316	0.518
24	Seyitömer / S-19	10	0.869	1.238	1.207	8.971	-	-	-	-	0.308	0.619

Table 8. Continued

CODE NO	Region & Panel	Dipper Capacity (yd^3)	*(Digging) Mean of Average Digging Power (MW)	*(Digging) Maximum Digging Power (MW)	*(Digging) Average of Maximum Digging Power (MW)	*(Digging) Average Digging Energy Consumption (MW.sec)	(Loose Material) Mean of Average Digging Power (MW)	(Loose Material) Maximum Digging Power (MW)	(Loose Material) Average of Maximum Digging Power (MW)	(Loose Material) Average Digging Energy Consumption (MW.sec)	(Empty Digging Mation) Average Power (MW)	(Empty Digging Motion) Maximum Power (MW)
25	Seyitömer / S-19	10	0.740	1.080	1.073	4.730	-	-	-	-	-	-
26	Seyitömer / S-18	10	0.840	1.274	1.238	5.063	0.628	1.008	0.931	3.722	0.301	0.481
27	Seyitömer / S-18	10	1.092	1.749	1.551	8.287	-	-	-	-	-	-
28	Yatağan / Eskihisar	15	0.671	1.143	1.075	7.945	0.637	1.161	1.047	5.668	0.267	0.448
29	Yatağan / Eskihisar	15	0.683	1.234	1.114	5.447	-	-	-	-	-	-
30	Yatağan / Eskihisar	15	0.762	1.397	1.131	9.043	0.710	1.089	1.089	5.969	-	-
31	Yatağan / Eskihisar	10	1.334	2.177	2.048	16.966	1.091	1.678	1.678	9.356	0.448	0.794
32	Yatağan / Eskihisar	10	1.326	2.291	1.982	16.720	1.197	1.746	1.690	6.849	-	-

Table 8. Continued

CODE NO	Region & Panel	Dipper Capacity (yd^3)	*(Digging) Mean of Average Digging Power (MW)	*(Digging) Maximum Digging Power (MW)	*(Digging) Average of Maximum Digging Power (MW)	*(Digging) Average Digging Energy Consumption (MW.sec)	(Loose Material) Mean of Average Digging Power (MW)	(Loose Material) Maximum Digging Power (MW)	(Loose Material) Average of Maximum Digging Power (MW)	(Loose Material) Average Digging Energy Consumption (MW.sec)	(Empty Digging Mation) Average Power (MW)	(Empty Digging Motion) Maximum Power (MW)
33	Yatağan/ Eskihisar	15	0.891	1.240	1.154	8.487	-	-	-	-	0.862	1.179
34	Yatağan/ Eskihisar	15	0.976	1.512	1.400	6.896	-	-	-	-	0.387	0.499
35	Tınaz	15	1.032	1.555	1.305	13.144	-	-	-	-	0.435	1.115
36	Tınaz	15	0.946	1.429	1.233	16.378	0.830	1.089	1.089	9.670	0.367	0.544
37	Tınaz	15	0.895	1.296	1.198	14.365	-	-	-	-	0.331	0.562
38	Tınaz	15	1.025	1.406	1.308	13.520	0.945	1.191	1.191	9.599	-	-
39	Milas/ İkizköy	15	0.884	1.382	1.305	10.688	0.800	1.181	1.091	6.453	0.353	0.518
40	Milas/ İkizköy	10	0.758	1.080	1.025	8.175	0.729	1.022	0.988	5.433	0.431	0.720

Table 8. Continued

CODE NO	Region & Panel	Dipper Capacity (yd^3)	*(Digging) Mean of Average Digging Power (MW)	*(Digging) Maximum Digging Power (MW)	*(Digging) Average of Maximum Digging Power (MW)	*(Digging) Average Digging Energy Consump-tion (MW.sec)	(Loose Material) Mean of Average Digging Power (MW)	(Loose Material) Maximum Digging Power (MW)	(Loose Material) Average of Maximum Digging Power (MW)	(Loose Material) Average Digging Energy Consump-tion (MW.sec)	(Empty Digging Mation) Average Power (MW)	(Empty Digging Motion) Maximum Power (MW)
41	Milas/ İkizköy	15	0.997	1.440	1.363	10.150	0.826	1.282	1.138	7.476	-	-
42	Milas/ İkizköy	15	0.927	1.613	1.430	13.625	-	-	-	-	-	-
43	Milas/ Sekköy	15	1.085	1.555	1.328	7.576	-	-	-	-	-	-
44	Sivas/ Kangal	25	1.011	1.598	1.461	11.840	0.804	1.382	1.382	7.754	0.327	0.605
45	Sivas/ Kangal	25	1.277	2.304	1.992	15.588	1.169	1.685	1.663	14.407	0.752	1.238
46	Sivas/ Kangal	10	1.072	1.696	1.536	11354	-	-	-	-	0.323	0.634
47	Sivas/ Kangal	20	1.400	1.500	1.500	13.034	-	-	-	-	0.5	0.6
+39	Milas/ İkizköy	15	0.906	1.339	1.277	9.842	0.759	1.080	1.029	5.414	0.353	0.518

+(Results of example solution)

*(Digging With or Without Blasting, Not Loose)

2. Maximum Digging Power (MW)

It is the maximum of peak powers recorded during the whole digging time. Records indicate that it also refers the maximum value which is obtained during whole performance measurement.

3. Average of Maximum Digging Powers (MW)

The maximum digging powers are found for each digging cycle. Then the summation of maximum digging powers divided by the number of observations to find the average of maximum digging powers for each location .

4. Average Digging Energy Consumption (MW.sec)

Energy consumption of total digging time is first calculated and divided by the number of digging to find the average digging energy consumption for each location.

The power consumption of electrical shovels during the loose material loading are also measured at some locations for 5 to 10 cycles. The above parameters are also calculated for those measurements.

6. Average Empty Digging Motion Power (MW) and Maximum Empty Digging Motion Power (MW)

Actual cycle measurement repeated as if the dipper is digging while the dipper is empty. The averages and maximum of these measurements are expressed as average empty digging motion power and maximum empty digging motion power respectively.

In order to clarify the terminology and calculation procedure the following example is solved and its record is illustrated in Figure 10.

These are the variables for this example:

Recorder Volt (RV) = 10V

Voltage Transformer Turns Ratio (VTTR)=6000/100=60

Current Transformer Turns Ratio (CTTR)= 300/5=60

Number of Current Transformer (CTN)=3

Wattmeter Current Range (WIR) = 5A

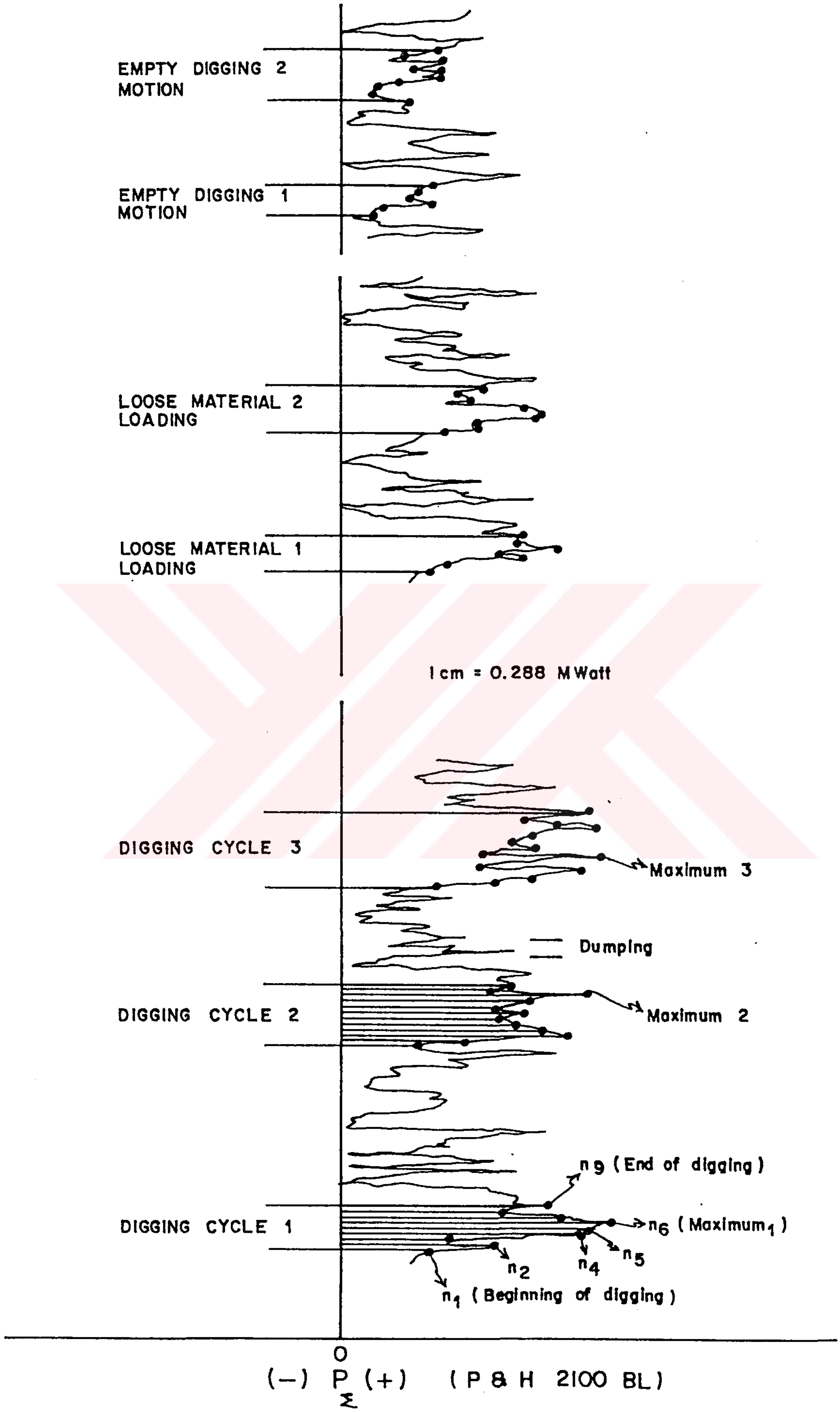

Figure 10. A typical record of power measurement

Wattmeter Voltage Range (WVR) = 300V

Recorder Velocity= 6cm/min

First power scale is determined

A= RV * 10mm/250mm = 0.4 Volt

B= WIR * WVR * VTTR * CTTR * 3 = 5400000 Watt

$$1\text{cm on the record corresponds} = \frac{A*B}{7500000} * \frac{3}{CTN} = 0.288 \text{ MWatt}$$

This calculation procedure above is also explained in Chapter 3.

For digging cycle 1, it is seen that the record is divided into 1mm. divisions. Then for every division, length of record is measured and multiplied with 0.0288 to convert it to power.

n_1 = 15 mm = 15 * 0.0288 = 0.432 MW

n_2 = 26.5 mm = 0.763 MW

n_3 = 18 mm = 0.518 MW

n_4 = 41 mm = 1.1808 MW

n_5 = 42.5 mm = 1.224 MW

$n_6 =$ 46.5 mm = 1.339 MW

$n_7 =$ 37.5 mm = 1.08 MW

$n_8 =$ 28 mm = 0.806 MW

$n_9 =$ 36 mm = 1.0368 MW

The averages of these n observation is formulazied as:

$$\text{Average Digging Power} = \frac{\sum_{i=1}^{n} P_i}{n}$$

where; n= number of observations for a single digging cycle (measured lengths)

$$\underset{\text{(for digging cycle 1)}}{\text{Average Dipping Power}} = \frac{0.432+0.763+0.518+1.1808+1.224+1.339+1.08+0.806+1.0368}{9}$$

= 0.931 MW

This operation is done for all digging cycles and in this example only 3 digging cycles are calculated. Then the mean of average digging powers is found for each location. These three digging cycles belong to measurement 39 and the results of this example are also given in Table 8.

Average Digging Power of Cycle 2 = 0.842 MW

Average Digging Power of Cycle 3 = 0.944 MW

Mean Of Average Digging Power= (0.931+0.842+0.944)/3 = 0.906MW

For all cycles, a maximum power is found as it is seen easily from the illustrated Figure 10. that the maximum length is equal to maximum power.

Maximum Power $_1$ = 1.339MW (n_6)

Maximum Power$_2$ = 1.195

Maximum Power$_3$ = 1.296

The highest of maximum power is found, in this example Maximum power is 1.339 MW.

Then average of maximum power is calculated:

Average of maximum digging power= (1.339+1.195+1.296)/$_3$=1.277 MW

Energy consumption of digging cycle 1 is found as follows:

First the area of the digging cycle is calculated.

$$\text{Area (cm}^2) = \left(\sum_{i=1}^{n} L_i - (L_1/2) - (L_n/2) \right) * 1\ \text{mm}/100$$

where ; L is the measured lenght.

For the digging cycle 1,

$$\text{Area} = \left(291 - \frac{15}{2} - \frac{36}{2}\right) * \frac{1}{100}$$

$$= 2.655\ \text{cm}^2$$

Then the formula given in Chapter 3 is used,

$$\text{Energy Consumption (MW.sec)} = \frac{\text{Area (cm}^2)}{X * y/60}$$

where; x is 1cm/MWatt

y is the recorder velocity in cm/min

$$\text{Digging Energy Consumption of Cycle 1} = \frac{2.655}{1/0.288 * \frac{6}{60}} = 7.646\ \text{MWatt*sec}$$

Digging Energy Consumption of Cycle 2= 9.511 MWatt*sec

Digging Energy Consumption of Cycle 3= 12.370 MWatt*sec

Average Digging Energy Consumption
= (7.646+9.511+12.370)/3= 9.842 MW*sec

All these parameters are also calculated for 2 loose material loading cycles which are illustrated in Figure 10 and the results are given in Table 8.

5.2. Analysis and Discussion of the Results

Among the parameters listed in Tables 7 and 8, the following parameters are studied to analyze and to classify the excavation conditions of formations.

1. Average cycle time (sec)

2. Average dipper fill factor

3. Hourly capacity without waiting (m^3/hr)

4. Mean of average digging power (MW)

5. Maximum digging power (MW)

6. Average of maximum digging power (MW)

7. Average digging enegy consumption (MW sec)

It is also stressed that not only the above parameters, but also the working conditions, operator experience and electric shovel conditions such as age, model, loose material loading power are also considered during the classification of formations.

Cycle time is mainly dependent on machine size and excavation conditions. When there is any deviation of swing angle from 90^0 ,it is especially considered in the analysis. The average cycle times for each location are compared with the literature values.Figure 11. exposes the evaluation of cycle time data with respect to the literature values.

The dipper fill factor is as effective as cycle time on the shovel productivity. It is difficult to excavate and fill the dipper as the formations tend to be hard. The average dipper fill factors are also compared with the literature values. Figure 12. shows the classifications of formations with respect to dipper fill factor.

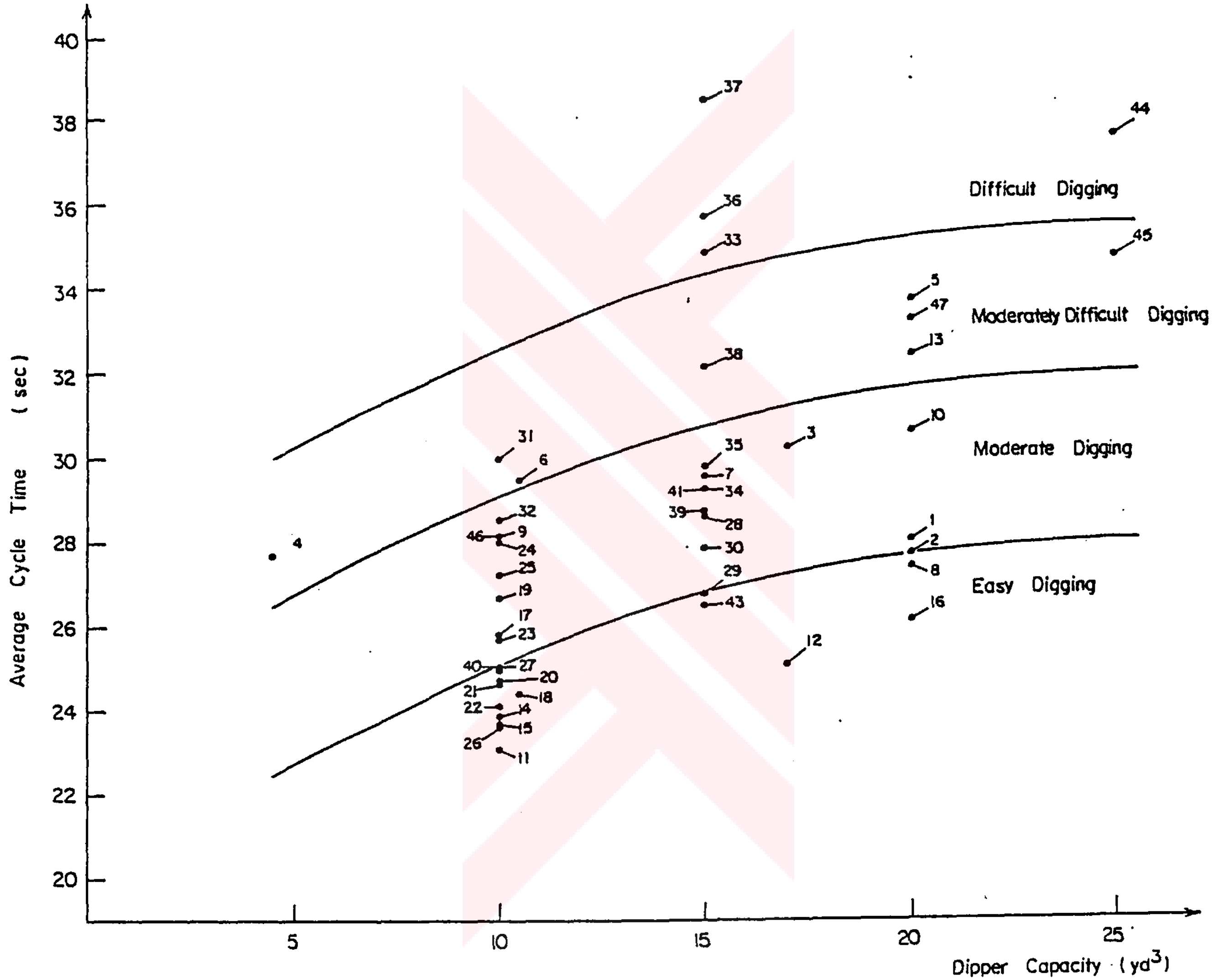

Figure 11. The relationship between the average cycle time and the digging difficulty of formations

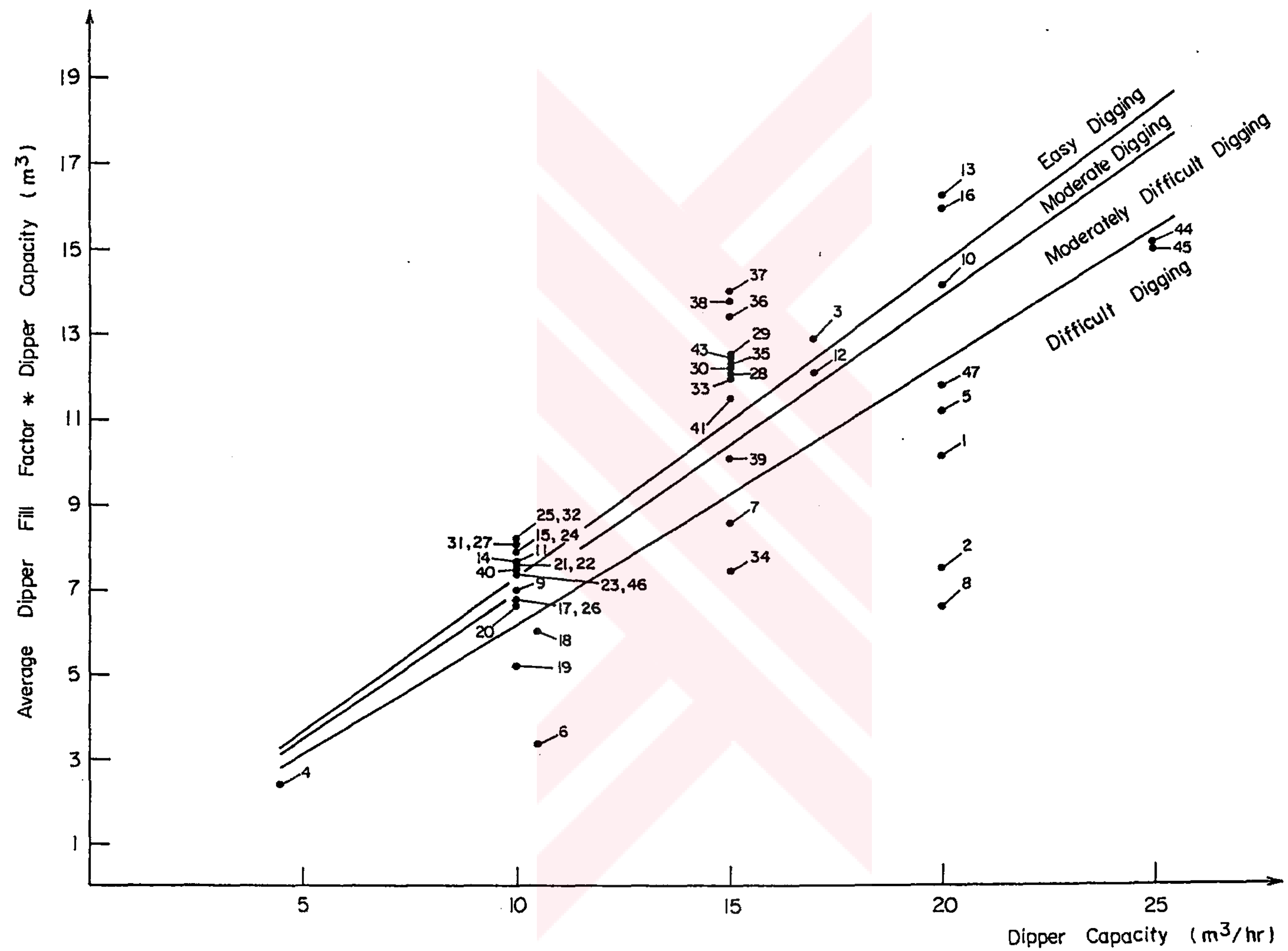

Figure 12. Classifications of formations with respect to dipper fill factor

Similarly, the hourly capacities without waiting are also compared with the literature values. Figure 13. shows the relationship between the hourly capacity without waiting and the excavation conditions of formations. Hourly capacity without waiting is especially preffered in the diggability classification, since it doesn't include down times.

The average digging power, maximum power and energy consumption of digging are directly propotional with the machine size and the formation digging difficulty, too.

The average powers of empty digging motion are analyzed to see the machine size effect on the digging power consumptions. Figure 14. shows the relationship between the average power of empty digging motion and dipper capacity with a 70% correlation coefficient.

The average powers of loose material loading are relatively greater than average powers of empty digging motion for each shovel, as it is expected. The relationship between the average power of loose material loading and the dipper capacity is shown in Figure 15. The power consumption of loose material loading is measured as a base value in order to be able to compare the digging conditions. It is observed that the average digging power

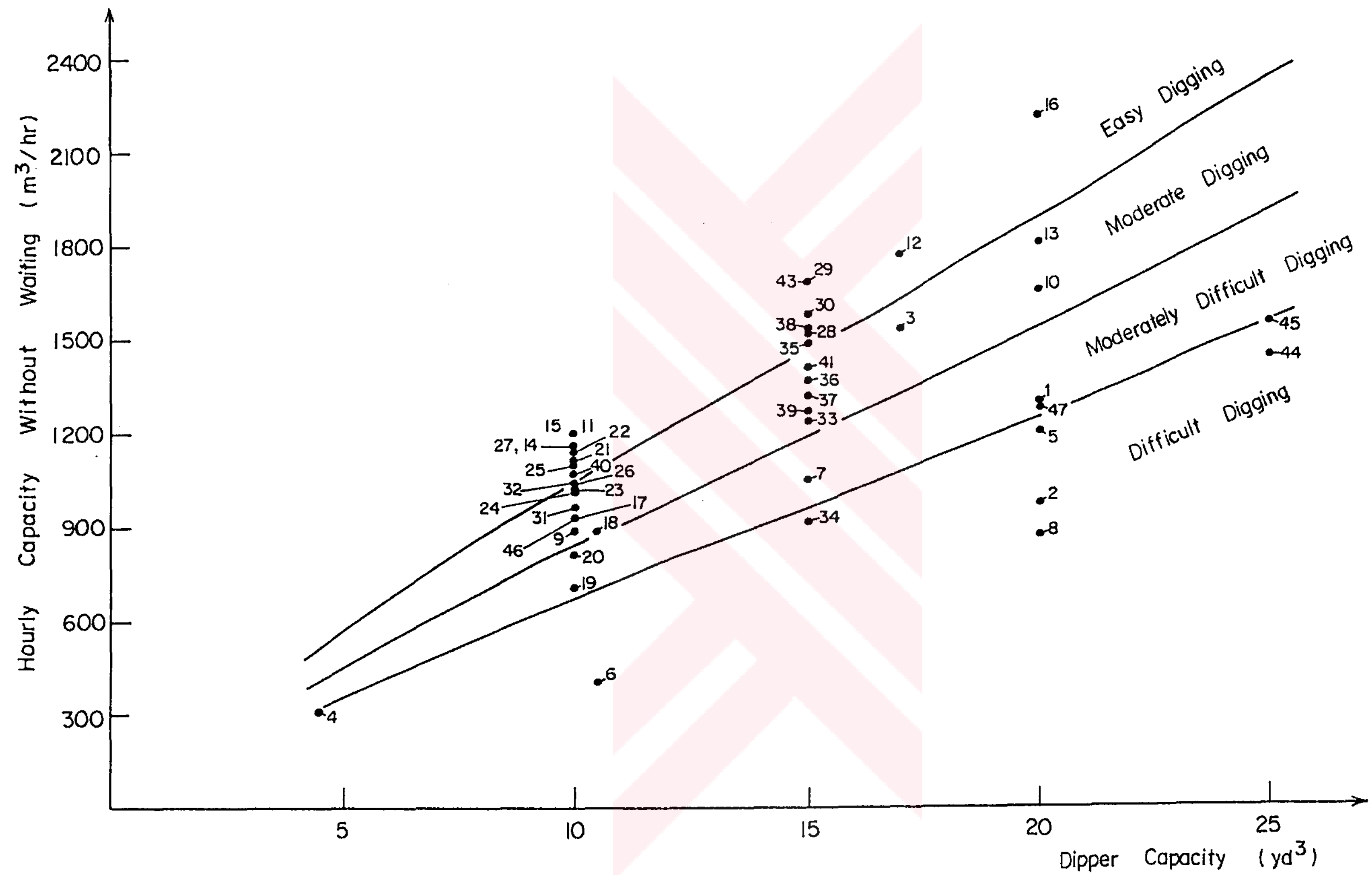

Figure 13. The relationship between the hourly capacity without waiting and the digging difficulty of formations

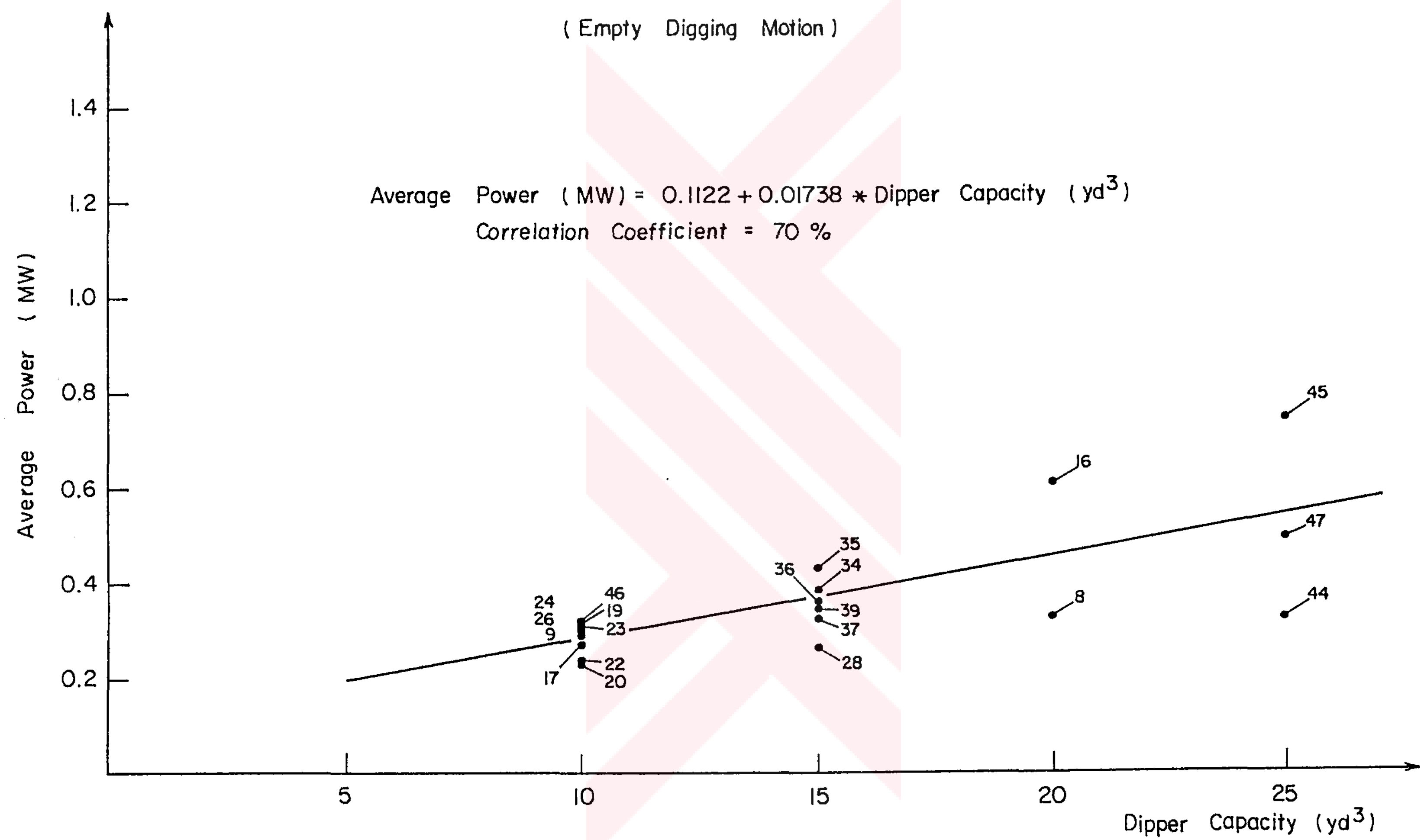

Figure 14. Relationship between average power and dipper capacity

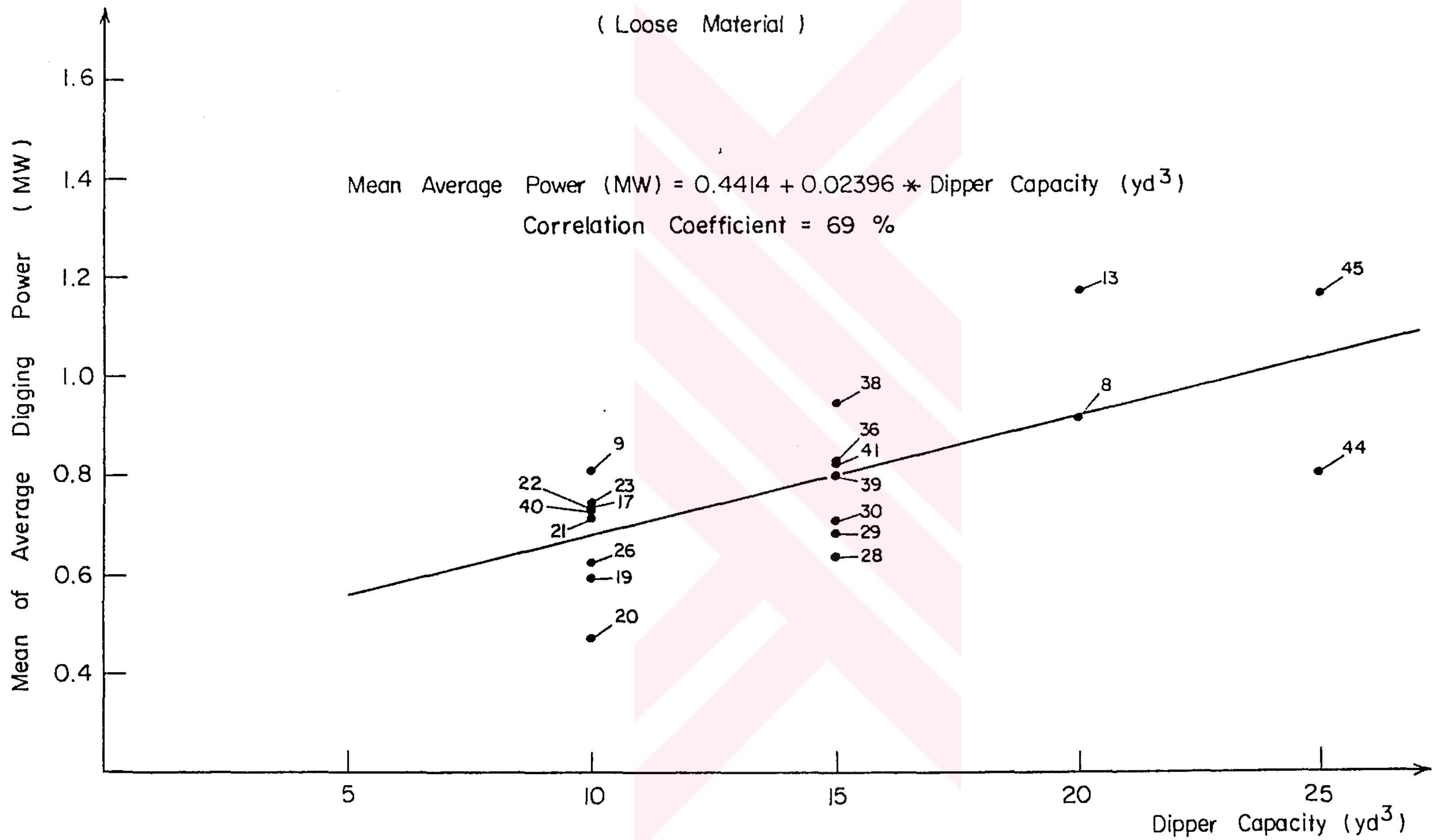

Figure 15. Relationship between mean of average digging power and dipper capacity

can be an indicator of digging difficulty of formations. The measured values are plotted to see the relative changes of mean of average power with respect to digging difficulties. The relationship between the mean of average power and the digging difficulty is shown in Figure 16. The line which separates the easy digging and the moderate digging is taken from Figure 15. The other two lines are drawn considering the formation characteristics which was accompanied with diggability classification system carried out A.G. Paşamehmetoğlu, et al. (1988).

The maximum powers obtained during empty digging motion are just plotted to see the relative decreases acording to the maximum power of loose material loading. The relationship between maximum power of empty digging motion and dipper capacity is shown in Figure 17. The maximum digging power is measured when the depth of cut is relatively more than the other digging cycles. It is also observed when the shovel is digging hard formations with difficulty. Figure18. shows the relationship between the maximum power of loose material loading and dipper capacity with a correclation coefficient of 79 % where it is used as a base to separate the easy and moderate diggability classification of formations in Figure 19. The diggability classification of formation with respect to maximum digging power is shown in Figure 19.

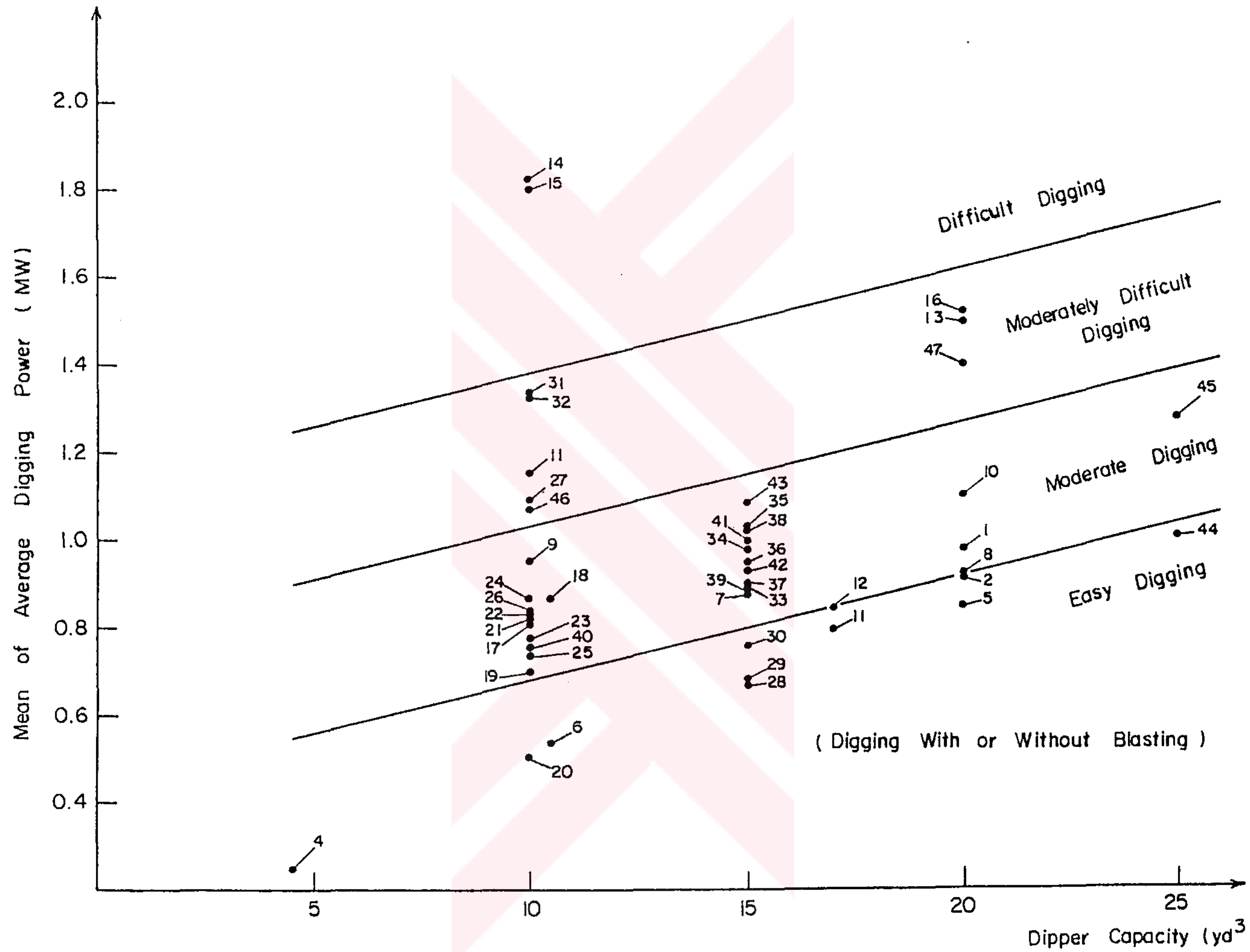

Figure 16. Relationship between mean of average digging power and digging difficulty

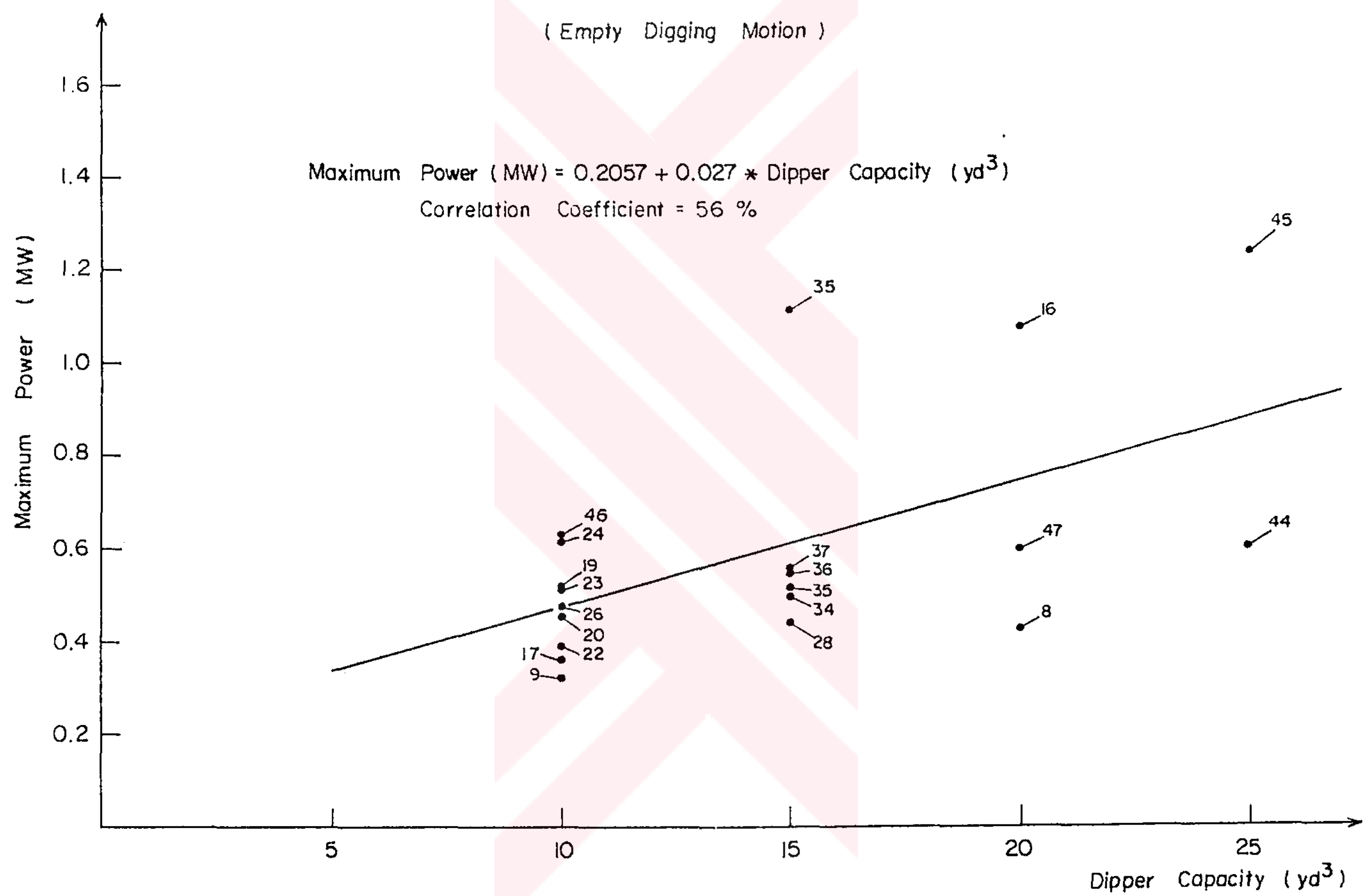

Figure 17. Relationship between maximum power and dipper capacity

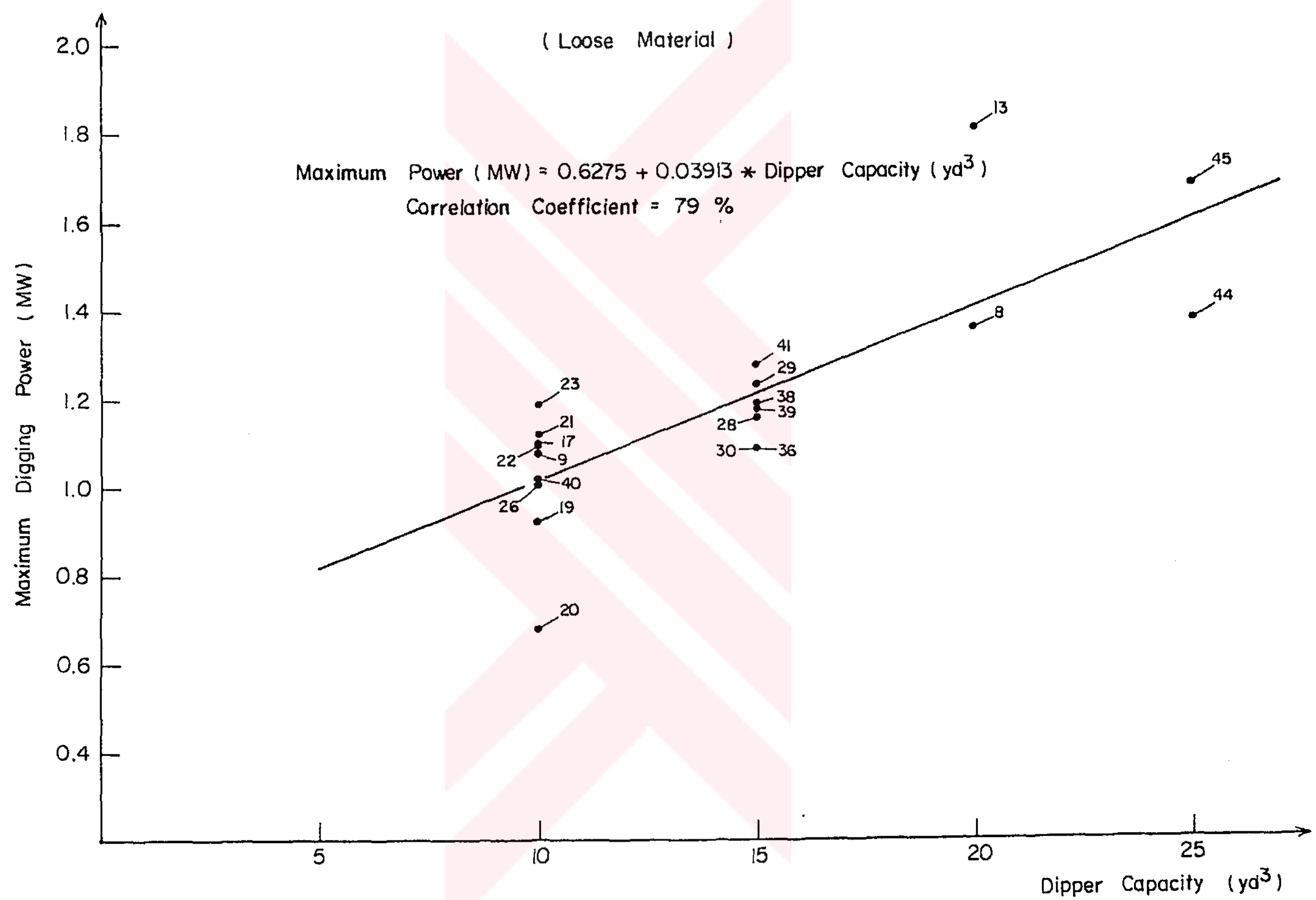

Figure 18. Relationship between maximum digging power and dipper capacity

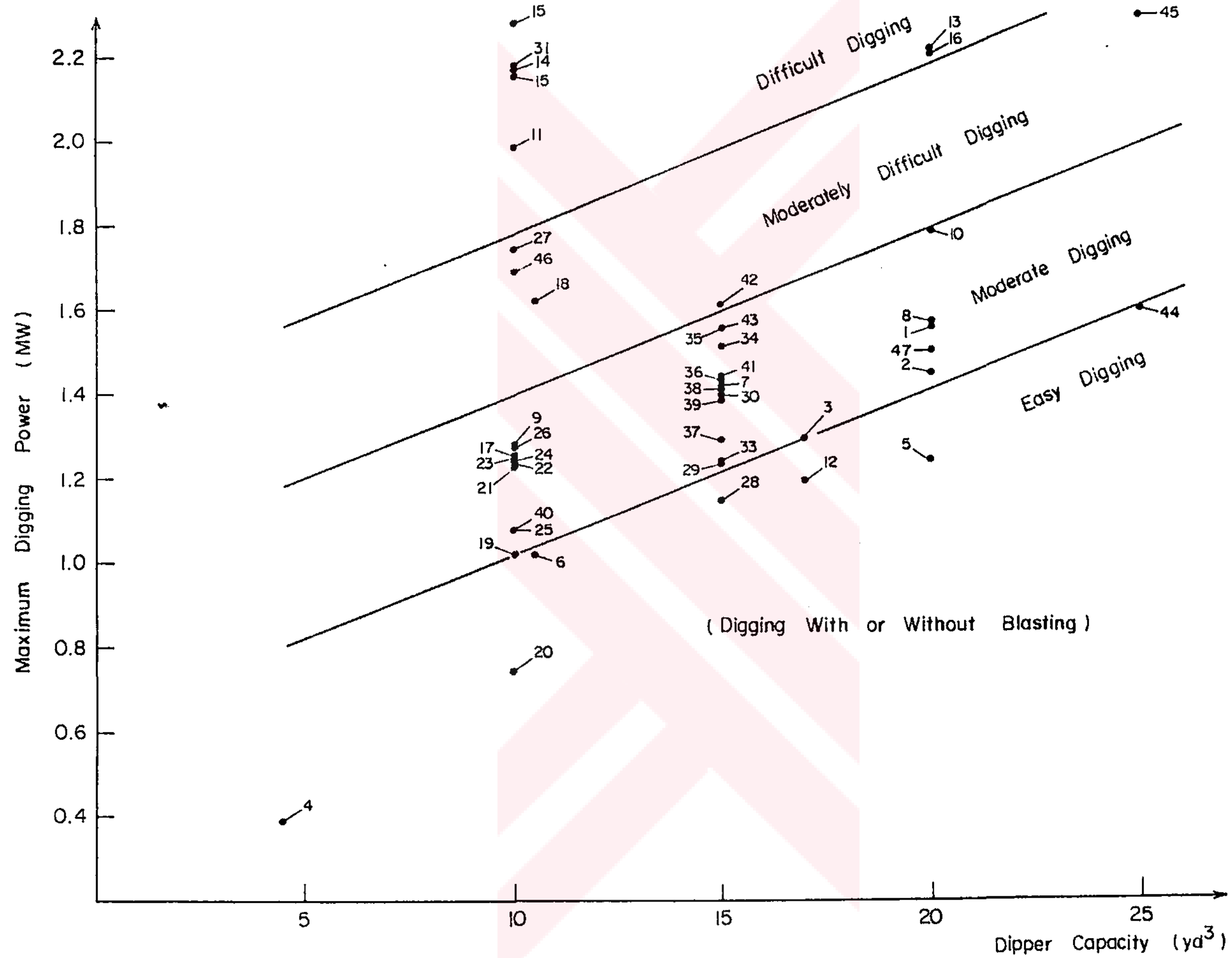

Figure 19. Relationship between maximum digging power and digging difficulty

The average of maximum power values are analyzed in the same manner to see the effects of maximum powers of each digging cycle on the digging difficulty of formations. Figure 20. shows the relationship between the loose material average of maximum power and dipper capacity with a 81 % correlation coefficient. The diggability classification of formation with respect to the average of maximum digging power is shown in Figure21.

Time required to fill the dipper is mainly dependent on the machine size and digging difficulty of formations. The digging power and time can be effectively analyzed with the energy consumption of shovel during the excavation. Figure 22. shows the relationship between the loose loading average energy consumption and dipper capacity where it is used as a base line to separate easy and moderate classifications of digging with respect to the average digging energy consumption. The diggability classification of formation with respect to the average energy consumption is shown in Figure 23.

Classifications of excavation condition with respect to the performance parameters shown in Figure 11,12, 13, 16, 19, 21, and 23 are also given in Table 9.

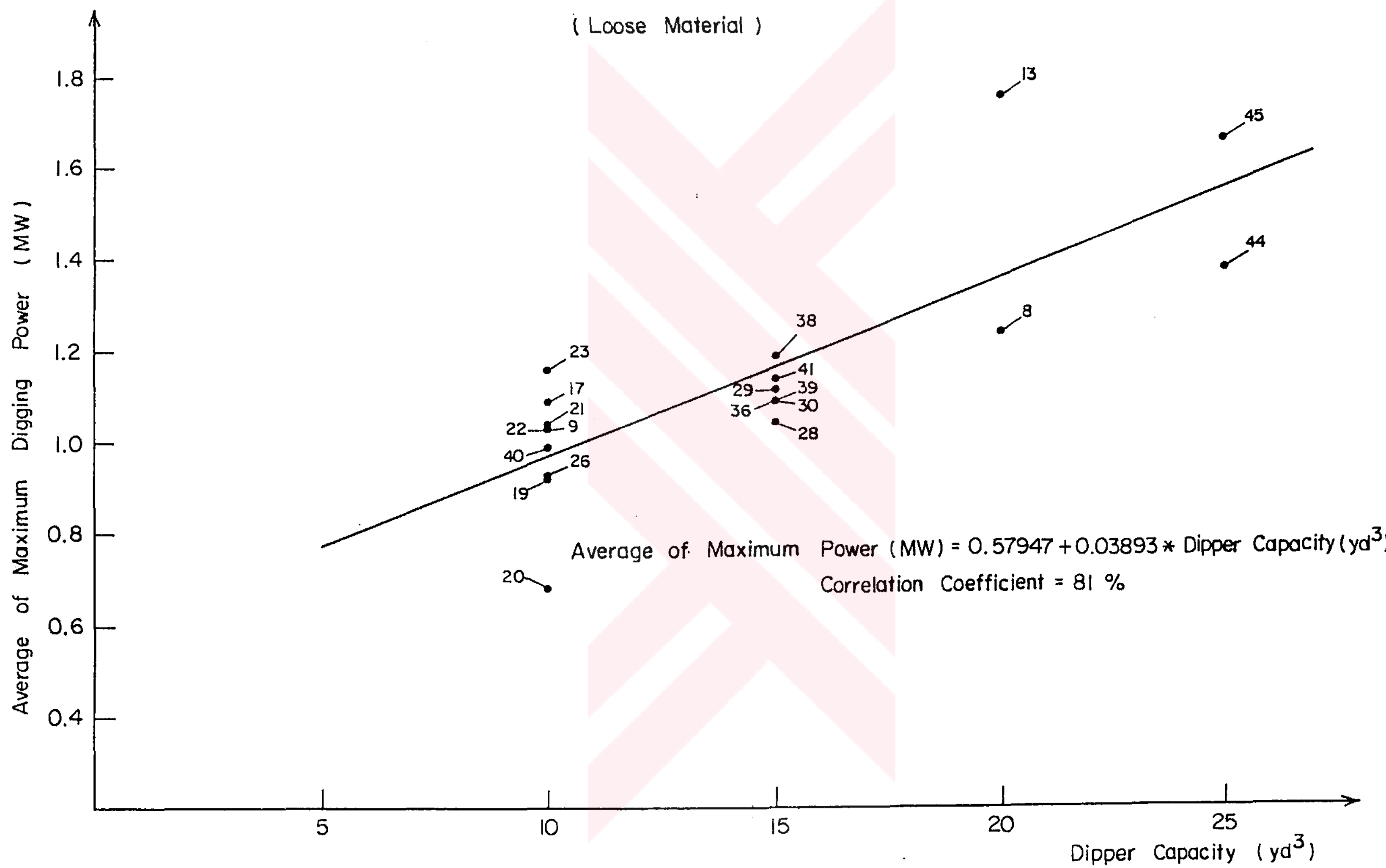

Figure 20. Relationship between average of maximum digging power and dipper capacity

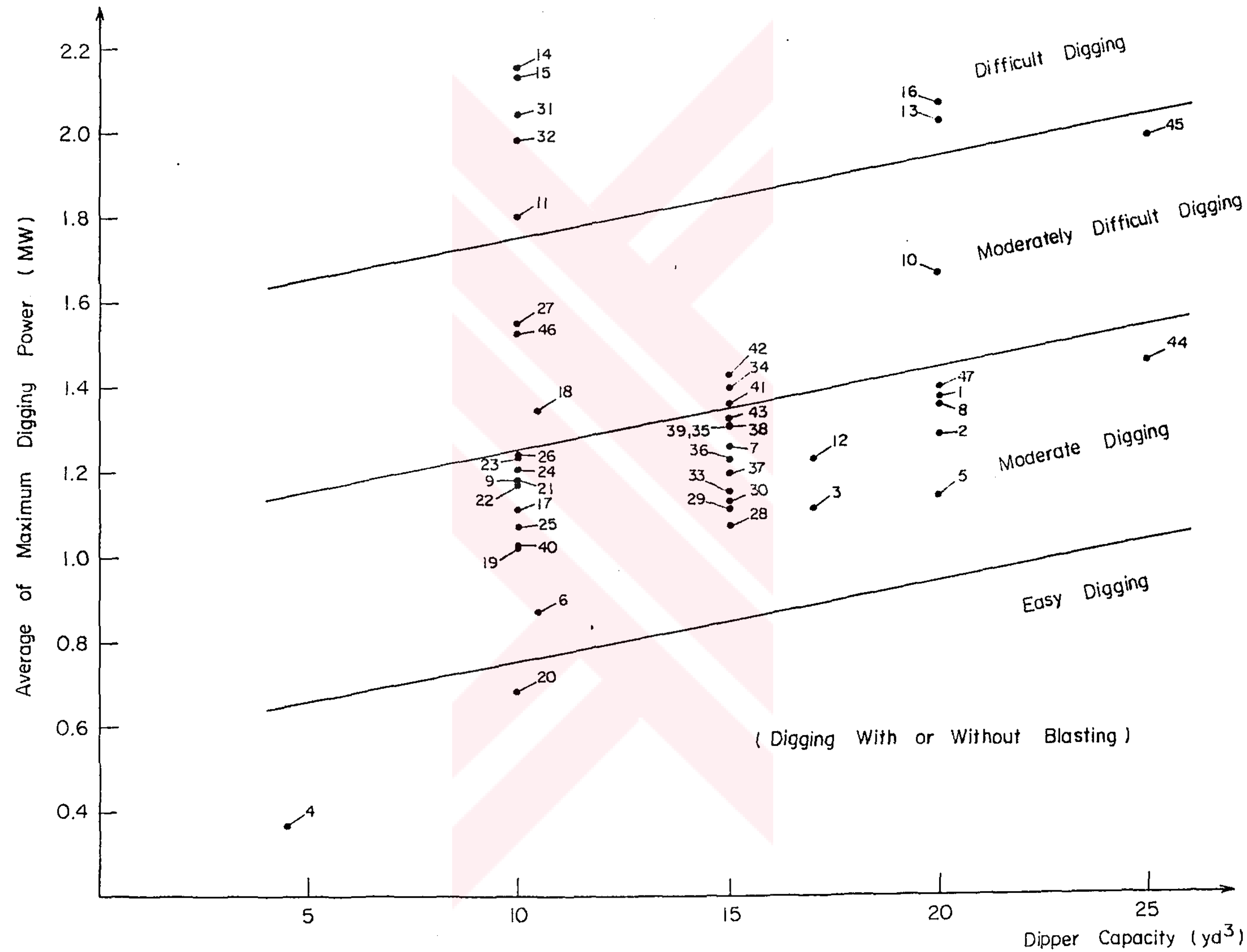

Figure 21. Relationship between average of maximum digging power and digging difficulty

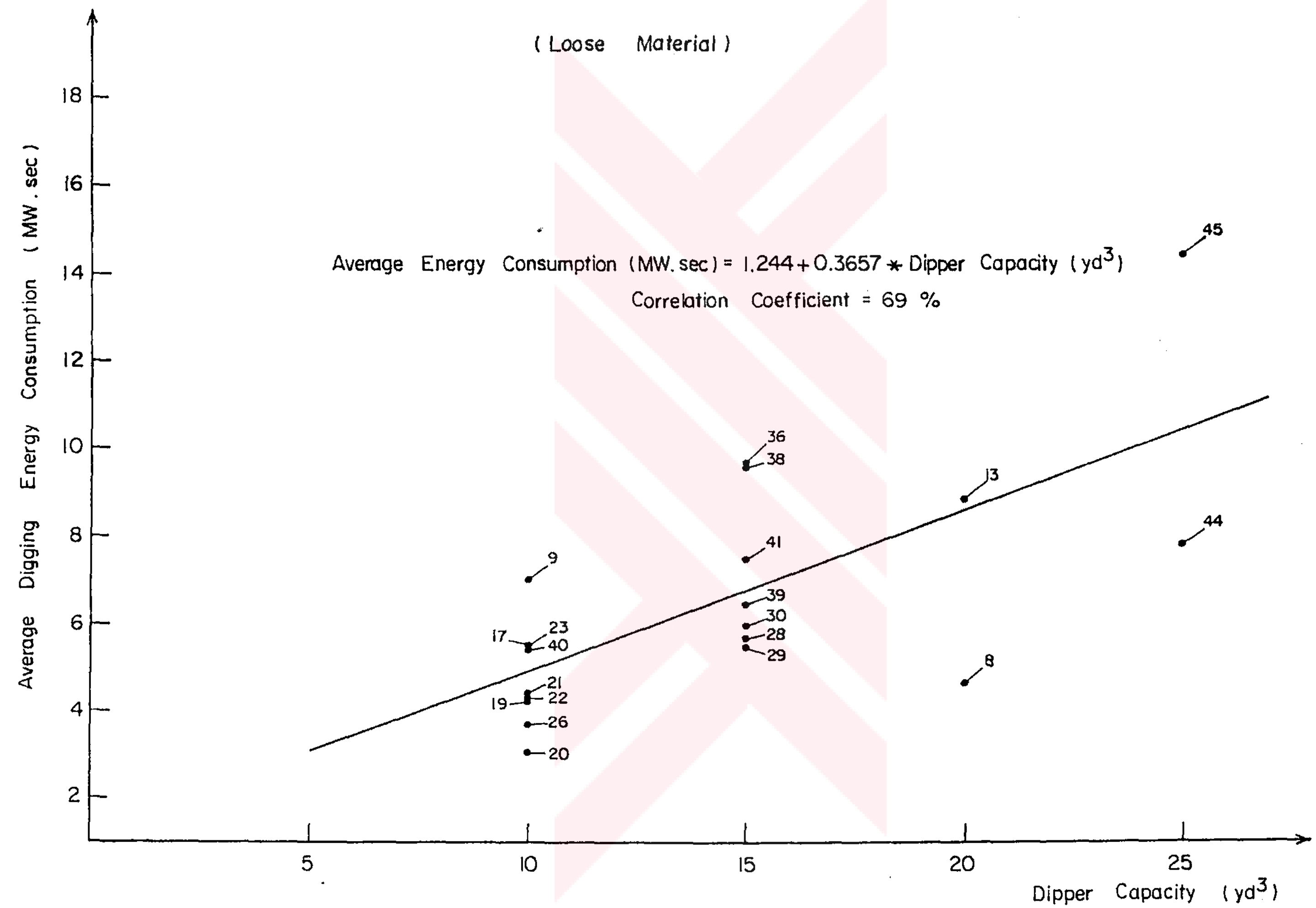

Figure 22. Relationship between average digging energy consumption and dipper capacity

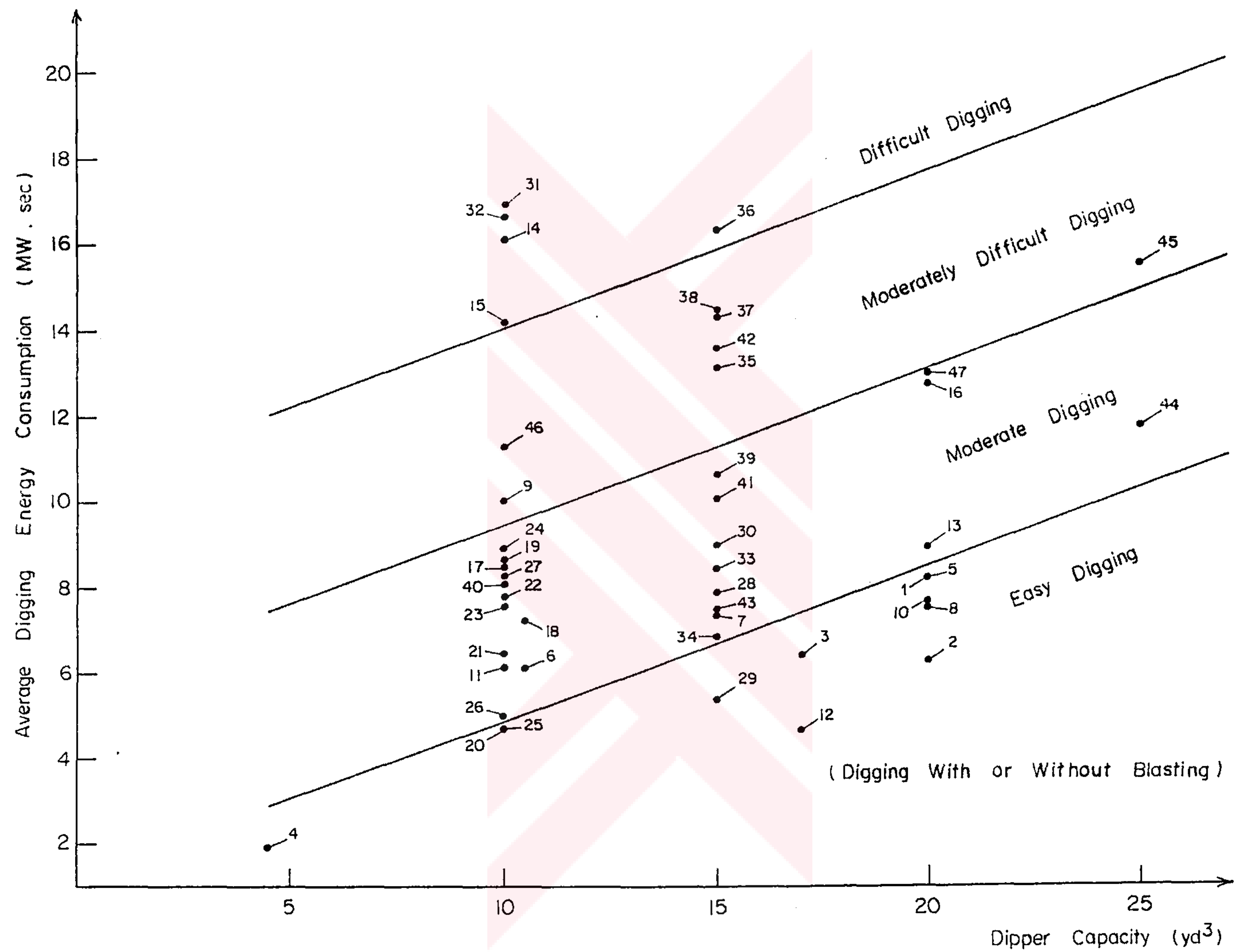

Figure 23 . Relationship between average digging energy consumption and digging difficulty

Table 9. Classifications of Excavation Conditions of Formations With Respect To Performance Parameters

CODE NO.	Classification Systems / Region & Panel	Average Cycle Time	Average Dipper Fill Factor	Hourly Capacity Without Waiting	Mean of Average Digging Power	Maximum Digging Power	Mean Maximum Digging Power	Average Digging Energy Consumption
1	Soma Kısrakdere- Doğu	Moderate	Difficult	Moderately Difficult	Moderate	Moderate	Moderate	Easy
2	Soma Işıklar- DE Pano	Easy	Difficult	Difficult	Easy	Moderate	Moderate	Easy
3	Soma Kısrakdere- Batı	Moderate	Easy	Moderate	Easy	Moderate	Moderate	Easy
4	Soma Kısrakdere- Batı	Moderately Difficult	Difficult	Difficult	Easy	Easy	Easy	Easy
5	Soma Işıklar- A Pano	Moderately Difficult	Difficult	Difficult	Easy	Easy	Moderate	Easy
6	Soma Elmalı	Moderately Difficult	Difficult	Difficult	Easy	Easy	Moderate	Moderate
7	Soma Sarıkaya	Moderate	Difficult	Moderately Difficult	Moderate	Moderate	Moderate	Moderate
8	Deniş Çamtarla	Easy	Difficult	Difficult	Moderate	Moderate	Moderate	Easy

Table 9. Continued

CODE NO.	Classification Systems / Region & Panel	Average Cycle Time	Average Dipper Fill Factor	Hourly Capacity Without Waiting	Mean of Average Digging Power	Maximum Digging Power	Mean Maximum Digging Power	Average Digging Energy Consumption
9	Deniş Çamtarla	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderately Difficult
10	Tunçbilek Beke	Moderate	Moderate	Moderate	Moderate	Moderate	Moderately Difficult	Easy
11	Tunçbilek Beke	Easy	Easy	Easy	Moderately Difficult	Difficult	Difficult	Moderate
12	Tunçbilek Beke	Easy	Moderate	Easy	Easy	Easy	Moderate	Easy
13	Tunçbilek Ömerler	Moderately Difficult	Easy	Moderate	Moderately Difficult	Difficult	Difficult	Moderate
14	Tunçbilek Ömerler	Easy	Easy	Easy	Difficult	Difficult	Difficult	Difficult
15	Tunçbilek Ömerler	Easy	Easy	Easy	Difficult	Difficult	Difficult	Difficult
16	Tunçbilek 36. Pano	Easy	Easy	Easy	Moderately Difficult	Difficult	Difficult	Moderate

Table 9. Continued

CODE NO.	Classification Systems / Region & Panel	Average Cycle Time	Average Dipper Fill Factor	Hourly Capacity Without Waiting	Mean of Average Digging Power	Maximum Digging Power	Mean Maximum Digging Power	Average Digging Energy Consumption
17	Tunçbilek 36. Pano	Moderate	Moderately Difficult	Moderate	Moderate	Moderate	Moderate	Moderate
18	Tunçbilek Kuşpınar	Easy	Difficult	Moderate	Moderate	Moderately Difficult	Moderately Difficult	Moderate
19	Tunçbilek Kuşpınar	Moderate	Difficult	Moderately Difficult	Moderate	Moderate	Moderate	Moderate
20	Seyitömer S-20	Easy	Moderately Difficult	Moderate	Easy	Easy	Easy	Easy
21	Seyitömer S-20	Easy	Easy	Easy	Moderate	Moderate	Moderate	Moderate
22	Seyitömer S-20	Easy	Easy	Easy	Moderate	Moderate	Moderate	Moderate
23	Seyitömer S-20	Moderate	Easy	Moderate	Moderate	Moderate	Moderate	Moderate
24	Seyitömer S-19	Moderate	Easy	Moderate	Moderate	Moderate	Moderate	Moderate

Table 9. Continued

CODE NO.	Classification Systems / Region & Panel	Average Cycle Time	Average Dipper Fill Factor	Hourly Capacity Without Waiting	Mean of Average Digging Power	Maximum Digging Power	Mean Maximum Digging Power	Average Digging Energy Consumption
25	Seyitömer S-19	Moderate	Easy	Easy	Moderate	Moderate	Moderate	Easy
26	Seyitömer S-18	Easy	Moderately Difficult	Moderate	Moderate	Moderate	Moderate	Moderate
27	Seyitömer S-18	Easy	Easy	Easy	Moderately Difficult	Moderately Difficult	Moderately Difficult	Moderate
28	Yatağan Eskihisar	Moderate	Easy	Easy	Easy	Easy	Moderate	Moderate
29	Yatağan Eskihisar	Easy	Easy	Easy	Easy	Moderate	Moderate	Easy
30	Yatağan Eskihisar	Moderate	Easy	Easy	Easy	Moderate	Moderate	Moderate
31	Yatağan Eskihisar	Moderately Difficult	Easy	Moderate	Moderately Difficult	Difficult	Difficult	Difficult
32	Yatağan Eskihisar	Moderate	Easy	Moderate	Moderately Difficult	Difficult	Difficult	Difficult

Table 9. Continued

CODE NO.	Classification Systems / Region & Panel	Average Cycle Time	Average Dipper Fill Factor	Hourly Capacity Without Waiting	Mean of Average Digging Power	Maximum Digging Power	Mean Maximum Digging Power	Average Digging Energy Consumption
33	Yatağan Eskihisar	Difficult	Easy	Moderate	Moderate	Moderate	Moderate	Moderate
34	Yatağan Eskihisar	Moderate	Difficult	Difficult	Moderate	Moderate	Moderatly Difficult	Moderate
35	Tınaz	Moderate	Easy	Easy	Moderate	Moderate	Moderate	Moderatly Difficult
36	Tınaz	Difficult	Easy	Moderate	Moderate	Moderate	Moderate	Difficult
37	Tınaz	Difficult	Easy	Moderate	Moderate	Moderate	Moderate	Moderatly Difficult
38	Tınaz	Moderatly Difficult	Easy	Easy	Moderate	Moderate	Moderate	Moderatly Difficult
39	Milas İkizköy	Moderate	Moderatly Difficult	Moderate	Moderate	Moderate	Moderate	Moderate
40	Milas İkizköy	Easy	Easy	Easy	Moderate	Moderate	Moderate	Moderate

Table 9. Continued

CODE NO.	Region & Panel / Classification Systems	Average Cycle Time	Average Dipper Fill Factor	Hourly Capacity Without Waiting	Mean of Average Digging Power	Maximum Digging Power	Mean Maximum Digging Power	Average Digging Energy Consumption
41	Milas İkizköy	Moderate	Easy	Moderate	Moderate	Moderate	Moderately Difficult	Moderate
42	Milas İkizköy	Moderate	Easy	Moderate	Moderate	Moderately Difficult	Moderately Difficult	Moderately Difficult
43	Milas Sekköy	Easy	Easy	Easy	Moderate	Moderate	Moderate	Moderate
44	Kangal Kalburçayırı	Difficult	Difficult	Difficult	Easy	Easy	Moderate	Moderate
45	Kangal Kalburçayırı	Moderately Difficult	Difficult	Moderately Difficult	Moderate	Moderately Difficult	Moderately Difficult	Moderately Difficult
46	Kangal Kalburçayırı	Moderate	Easy	Moderate	Moderately Difficult	Moderately Difficult	Moderately Difficult	Moderately Difficult
47	Kangal Kalburçayırı	Moderately Difficult	Difficult	Moderately Difficult	Moderately Difficult	Moderate	Moderate	Moderate

Classification parameters of cycle time and power measurements are compared with each other considering the working conditions such as operator experience, blasting, shovel age and loose loading power. They are in good agreement with each other from the digging difficulty point of view. The studied formations are classified with respect to digging difficulty considering all above parameters. Final classifications of excavation condition of formations are given in Table 10. Tunçbilek- Ömerler highly to moderately weathered marl, Seyitömer shear zone of tuff, Seyitömer and Yatağan blasted marl are in easy digging condition while Tunçbilek - Ömerler moderately weathered marl, Tınaz conglomerate, Milas-İkizköy moderately weathered marl and limestone and Kangal-Kalburçayırı slightly to moderately weathered blasted limestone are in moderately difficult digging condition. Most of the formations are in moderate digging condition, as it is expected. Even if they are also interpreted with the other analysis conducted by A.G. Paşamehmetoğlu, et al. (1988). which is the sensitive of this study.

Table 10. Final Classifications of Excavation Conditions of Formations

CODE NO.	Region & Panel	Formation	Digging With or Without Blasting	Classifications of Excavation Conditions of Formations
1	Soma Kısrakdere-Doğu	Fresh-Slightly Weathered Marl	Blasted	Moderate
2	Soma Işıklar-DE Pano	Fresh-Slightly Weathered Marl	Blasted	Moderate
3	Soma Kısrakdere-Batı	Highly Weathered Marl	Blasted	Moderate
4	Soma Kısrakdere-Batı	Slightly to Moderately Weathered Marl	Blasted	Moderate
5	Soma Işıklar-A Pano	Moderately to Highly Weathered Tuff, Marl	-	Moderate
6	Soma Elmalı	Fresh to Slightly Weathered Marl	Blasted	Moderately Difficult
7	Soma Sarıkaya	Moderately to Highly Weathered Marl, Tuff	-	Moderate
8,9	Deniş Çamtarla	Fresh to Slightly Weathered Marl and Some Shear Zones	Blasted	Moderate

Tablo 10. Continued

CODE NO.	Region & Panel	Formation	Digging With or Without Blasting	Classifications of Excavation Conditions of Formations
10,11,12	Tunçbilek Beke	Fresh to Slightly Weathered Marl	Blasted	Moderate
13,14	Tunçbilek Ömerler	Moderately Weathered Marl and Some Shear Zones	-	Moderately Difficult
15	Tunçbilek Ömerler	Highly to Completely Weathered Marl	-	Easy
16	Tunçbilek 36. Pano	Completely Weathered Marl *(At the bottom fresh marl)	-	Easy * Difficult
17	Tunçbilek 36. Pano	Fresh to Slightly Weathered Marl	Blasted	Moderate
18	Tunçbilek Kuşpınar	Completely Weathered Marl	-	Moderate
19	Tunçbilek Kuşpınar	Slightly to Moderately Weathered Marl	-	Moderately Difficult
20	Seyitömer S - 20	Clayish Fresh Marl and Tuff	Blasted	Easy

Tablo 10. Continued

CODE NO.	Region & Panel	Formation	Digging With or Without Blasting	Classifications of Excavation Conditions of Formations
21	Seyitömer S- 20	Shear Zone, Tuff	-	Easy
22,23	Seyitömer S- 20	Slightly Weathered Marl	Blasted	Moderate
24,25	Seyitömer S- 19	Fresh to Moderately Weathered Marl	Blasted	Moderate
26,27	Seyitömer S- 18	Moderately to Highly Weathered Clayish Marl	-	Moderate
29	Yatağan Eskihisar	Slightly to Moderately Weathered Marl	Blasted	Easy
30,32,34	Yatağan Eskihisar	Slightly to Moderately Weathered Marl	-	Moderate
28,31,33	Yatağan Eskihisar	Highly Weathered Marl and Soil	-	Easy
35,36	Tınaz	Slightly Weathered Clayish and Sandy, Weakly Cemented Conglamerate	-	Moderately Difficult

Table 10. Continued

CODE NO.	Region & Panel	Formation	Digging With or Without Blasting	Classifications of Excavation Conditions of Formations
37, 38	Tınaz	Moderately to Highly Weathered Limestone and Marl	-	Moderate
39, 41	Milas İkizköy	Moderately to Highly Weathered Marl, Limestone and Soil	Blasted	Moderate
40	Milas İkizköy	Fresh to Slightly Weathered Marl	Blasted	Moderate
42	Milas İkizköy	Moderately to Highly Weathered Marl, Limestone	-	Moderately Difficult
43	Milas Sekköy	Weak Coal and Soil	-	Moderate
44	Kangal Kalburçayırı	Fresh to Slightly Weathered Clayish Marl	-	Moderate
45	Kangal Kalburçayırı	Hightly Weathered Limestone and Soil (Fresh Limestone at the Bottom)	Blasted	Moderately Difficult
46, 47	Kangal Kalburçayırı	Slightly to Moderately Weathered Limestone	Blasted	Moderately Difficult

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