DE GRUYTER
OPEN

Arch. Min. Sci., Vol. 59 (2014), No 2, p. 477–488

Electronic version (in color) of this paper is available: http://mining.archives.pl

DOI 10.2478/amsc-2014-0034

ABDURRAHMAN TOSUN*[1], GURCAN KONAK*, TUGÇE TOPRAK*, DOGAN KARAKUS*, AHMET HAKAN ONUR*

DEVELOPMENT OF THE KUZ-RAM MODEL TO BLASTING IN A LIMESTONE QUARRY

OPRACOWANIE MODELU KUZ-RAM DO WYKORZYSTANIA PRZY PRACACH STRZAŁOWYCH W KOPALNI WAPIENIA

It is very important to know the degree of disintegration beforehand in open quarry bench blasting in terms of blasting efficiency. Kuznetsov (1973), Cunningham (1987), and Ouchterlony (2005) have developed the Rosin-Rammler distribution function for estimating the degrees of fragmentation (Rosin & Rammler, 1933). However, models they developed do not give realistic results for blast surfaces where there are a lot of discontinuity characteristics with broken and fissured areas due to the difference in structural characteristics of the rocks. In this study, average fragmentative distribution of the heap formed as a result of several blasting tests in a quarry belonging to BATIÇİM have been separately determined by using a dimensional analysis program with Wipfrag image processing technique and Kuz-Ram estimation model. Average granular size correction has been carried out with the approach of accepting as fine-grain the areas that couldn't be determined by means of image analysis programs and that were neglected in the analysis. Subsequently, the land coefficient in Kuz-Ram model was determined to be 0.0383 rather than 0.06 for the said quarry by taking the average dimension values determined by Wipfrag method as reference point.

Keywords: average muck pile fragmentation, estimation muck pile fragmentation, blasting efficiency, Image processing technique

Kluczowym zagadnieniem jest znajomość stopnia rozdrobnienia materiału przed przystąpieniem do prac strzałowych w kamieniołomach, dla określenia skuteczności strzelania. Kuznetsov (1973), Cunninghma (1987) i Ouchterlony (2005) wyprowadzili dystrybuantę bazującą na równaniu Rosina--Rammlera (1933) w celu estymacji stopnia rozdrobnienia materiału. Jednakże opracowane modele nie oddają rzeczywistych wyników gdy prace strzałowe prowadzone są na powierzchniach w których znajdują się liczne strefy nieciągłości, załamań oraz spękań wskutek różnic we właściwościach struktur skalnych. W pracy tej obliczono średnią wielkość fragmentów materiałów rozdrabnianych w trakcie trwania prac strzałowych w kamieniołomie należącym do przedsiębiorstwa BATICIM. Wielkości te zostały określone oddzielnie przy użyciu programu do analiz wymiarowych wykorzystującego techniki przetwarzania

* DOKUZ EYLUL UNIVERSITY, ENGINEERING FACULTY, DEPARTMENT OF MINING ENGINEERING, BUCA-IZMIR/TURKEY
[1] CORRESPONDING AUTHOR: E-mail: abdurrahman.tosun@deu.edu.tr

obrazów Wipfrag oraz model estymacyjny oparty na modelu Kuz-Ram. Przeprowadzono korektę ze względu na wielkość uziarnienia, w podejściu tym jako obszary drobnoziarniste ujęto te obszary które nie mogły zostać zanalizowane przy użyciu technik przetwarzania obrazów i zostały pominięte w analizach. Współczynnik terenowy dla danego kamieniołomu według modelu Kuz-Ram został obliczony jako 0.0383 a nie 0.06, przy wykorzystaniu jako wielkości odniesienia średnich rozmiarów skał obliczonych z zastosowaniem metody Wipfraga.

Słowa kluczowe: średni rozmiar rozdrobnionych odłamków, szacowanie średniego rozdrobnienia, wydajność prac strzałowych, techniki przetwarzania obrazów

1. Introduction

Drilling and blasting process is not used for the production of rigid materials that is not economically and technically possible to excavate in open quarry industry. The production of aggregate starts with drilling and blasting and ends with loading, transportation, and size reduction. In quarry blasting, it is very important to estimate the average heap size distribution beforehand for creating blast designs resulting quarry operations with the least cost.

Several researchers have carried out a number of studies related to this subject. The Kuz-Ram model developed by Cunningham is the most common model used in estimating heap size distribution after blasting (1987). Cunningham integrated the empirical equation proposed by Kuznetsov (1973) for average size (x_{50}) estimation with the size distribution function proposed by Rosin and Rammler (1933).

Kuznetsov proposed the following formula relating rock mass between the explosive amount (specific charge) and the average size (1973).

$$X_{50} = A\left(\frac{V_o}{Q_e}\right)^{0.8} Q_e^{1/6} \tag{1}$$

where

- X_{50} — is average size (cm),
- A — is the rock factor,
- V_o — is the volume to be blasted per hole (segment thickness *x* distance between the holes *x* bench height, m^3),
- Q_e — is nitroglycerine based explosive used per hole.

As mentioned above, the average size distribution is for nitroglycerine based explosives with high detonation speeds. The power of these explosives is high when compared to the widely used Anfo. Therefore, a correction coefficient to the relation above is applied as in the relation below where the Anfo is used. If Anfo is used, S_{Anfo} =100

$$X_{50} = A\left(\frac{V_o}{Q_e}\right)^{0.8} Q_e^{\frac{1}{6}} \left(\frac{S_{Anfo}}{115}\right)^{-\frac{19}{30}} \tag{2}$$

One of the most important parameters used in bench blasting is the specific charge (q) amount defined as the amount of explosive used per unit volume. Calculation of the specific charge is given below.

$$\frac{1}{q}=\frac{V_0}{Q_e} \tag{3}$$

In this case, once the intended average size distribution is determined, the amount of specific charge can be calculated as given below by using the formulas above.

$$q=\left[\frac{A}{X_{50}}Q_e^{1/6}\left(\frac{115}{S_{Anfo}}\right)^{19/30}\right]^{1.25} \quad (\text{kg/m}^3) \tag{4}$$

While the amount of explosive being used and the amount of specific charge could be used as an important factor in the equations given for the estimation of size distribution, the value of rock factor was proposed between 7 and 13.

Cunningham tried to remedy the deficiency related to the fact that the rock factor doesn't reflect characteristic properties of the rock mass (1983). The formula proposed by Lilly related to the blastability of rock mass is given below and the variables used are given in the Table 1 (1986).

$$A=0,06\left(RMD+JF+RDI+HF\right) \tag{5}$$

TABLE 1

Definition and calculation of the variables used in the determination of Rock Factor A (Lilly, 1986)

RMD Rock mass number	
If the rock mass is of fragile brittle structure	RMD = 10
If there are discontinuities in vertical direction	RMD = JF
If it is of massive structure	RMD = 50
JF Rock Mass Discontinuity Coefficient	
JPS Vertical Discontinuity Range	JF =JPS+JPA
If average discontinuity range is < 0.1 m	JPS = 10
If average discontinuity range is 0,1 m < *X* < Massive Block Sized (~ 0.5 m)	JPS = 20
If average discontinuity range is massive block < *X* < Segment Thickness (m)	JPS = 50
JPA Discontinuity plane angle	
If the plane angle is towards the exterior of the surface	JPA = 20
If the plane angle is perpendicular to the surface	JPA = 30
If the plane angle remains inside the surface	JPA = 40
KDI Rock density factor	
Rock Density RD (t/m^3)	RDI = 25 RD-50
HF Hardness factor	
If Young Module is *Y* < 50	HF = Y/3
If Young Module is *Y* > 50	HF = s_b/5

The blasting index of the proposed rock mass is taken as basis in the determination of the rock factor used in average size estimation equation.

Due to the differences especially in the determination of rock mass number (RMD) in the practice, the value A was rendered by taking it as 7 for medium-hard rock masses, 10 for much fissured hard rock masses, and 13 for low fissured hard rock masses practically.

Rosin and Rammler defined the function of size distribution as follows (1933).

$$R_m = 1 - e^{-\left(\frac{X}{X_C}\right)^n} \tag{6}$$

where R_m is the ratio of material passing with determined size (%), X is the determined size (sieve aperture, mm), n is the uniformity index, and X_C is the scaling factor defined as characteristic dimension (mm). According to this equation, knowing the uniformity index (n) and the characteristic dimension (X_C) will be sufficient for being able to draw a distribution curve. For the determination of the characteristic size (X_C) the equation above can be expressed as follows when rearranged.

$$X_C = \frac{X}{\sqrt[n]{-\ln\left(1 - R_m\right)}} \tag{7}$$

Cunningham determined the value X_{50} by accepting the average size value proposed by Kuznetsov as ($X = X_{50}$) ve $R_m = 0.5$ (%50). Accordingly, the characteristic size formula given above can be written as follows.

$$X_C = \frac{X_{50}}{\sqrt[n]{0.693}} \tag{8}$$

Later on, some researchers tried to develop different models by suggesting that the Kuz-Ram model is limited or developed new coefficients that will remove the insufficiency of this model in their studies carried out related to size distribution estimation. However, these researchers used the average size value of the heap as in the equation given in Kuz-Ram estimation model in their studies. In this sense, the Kuz-Ram model has been a starting point for discussing whether heap size distribution occurring as a result of bench blasting can be estimated.

Five equations ensuring the determination of rock mass characteristics are used as the coefficient in the Kuz-Ram model estimating the average size value given in 2 equations. The coefficient 0.06 in the 5 equations proposed by Lilly (1986) for being able to determine rock mass characteristics was determined as the land coefficient. This coefficient gives near accurate values in massive rocks not containing homogenous discontinuity while it doesn't give near realistic values in non-homogenous rocks. A.A. Bazzazı and M. Esmaeılı determined different backbreak lengths caused by different rock mass characteristics in open pit blasting (2012).

Therefore, T. Hudaverdi et al. used fragmentation index instead of discontinuity properties in order to define mean fragment size of heap resulting from blasting (2012). However it doesn't give near realistic values in non-homogenous rocks. S. Gheibie et al. determined the average size values of the heap by carrying out a number of blasting experiments in non-homogenous rocks (2009). They changed the land coefficient to 0,071 in Kuz-Ram estimation model according to these size values they determined and enabled the estimation model by using image processing technique to give more realistic results. M. Monjezı et al. applied neural networks for the prediction of rock fragmentation (2012). They also used image processing technique. However, it is known that there are some deficiencies in the determination of size distribution with heap image processing technique occurring as a result of blasting. The fact that very fine grains in the heap cannot be taken into account in the determination of size distribution and the third dimensions of the grains cannot be seen over the heap come to the fore among these deficiencies.

A number of test blasts have been carried out in non-homogenous fissured rock with the Wipfrag computer program used in the determination of size values of the formed heaps. Determination of heap size distribution with image analysis method was first applied by Carlsson and Nyberg and they proposed a few basic rules that are still valid for being able to apply the method (1983). These are the requirement for the existence of a difference of at least 20 times between the biggest granular size and the smallest granular size and the necessity for image resolution of the smallest granular size to be at least 3 times. Differences more than 20 times can occur between the biggest granular size and the smallest granular size in the heap formed as a result of blasting. The smallest grains in the heap occur as very fine grains. Therefore, it is ensured that very fine grains in the heap are also considered in size distribution calculation determined by Wipfrag image processing technique by using some methods in image processing technique.

In order to prove the correctness of the average size values of the heap that is obtained, the hydraulic pressure changes occurring in oil pistons is used to determined whether the loader is forced during the loading of blasted material this is compared the with average size values of the heap determined with Wipfrag program. Subsequently, determined average heap size values were taken as reference point and it was ensured that the said estimation model gives more correct results by changing the land coefficient in Kuz-Ram model estimating the average size value of the heap.

2. Research method and field works

In this research study, in order to correctly determine the land coefficient in Kuz-Ram estimation model used in the calculation of average size value of the heap occurring as a result of blasting, field tests have been carried out in limestone quarries called as Arkavadi 1st Region and Arkavadi 2nd Region belonging to Western Anatolia Cement Plant (Batı Anadolu Cement Plant) located in Izmir, Turkey. Twelve blasting tests were carried out in total, eight in Arkavadi 1st Region quarry and four in Arkavadi 2nd Region quarry.

In regions where blasting tests were carried out, laboratory studies were carried out, discontinuity characteristics of blast surfaces were revealed, controllable technical parameters belonging to blasting were recorded, average size values of the heap formed as a result of blasting were analyzed with Wipfrag image processing program in order to determined physical and mechanical characteristics of the rock, and hydraulic piston pressure values of the loader are measured for being able to determine the performance of the loader in each blasting test.

2.1. Rock mechanics laboratory studies

Physical and mechanical tests were applied to the samples provided from the regions where blasting tests have been carried out in rock mechanics laboratories. As a result of these tests, the density and unit volume weight as well as uniaxial compression strength and indirect tensile strength values were determined (Table 2).

TABLE 2

Physical and mechanical characteristics of the studied material

Working Site	Average Unit Volume Weight (gr/cm³)	Average Density (gr/cm³)	Average Uniaxial Compression Strength (MPa)	Average Indirect Tensile Strength
Arkavadi Quarry	2.70±0.003	2.74±0.002	38.00±1.75	6.41±0.55

2.2. Determination of discontinuity characteristics of blast surfaces and controllable parameters belonging to the blasting

Stereonets of the rock mass surfaces were obtained with "Stereographic Projection Techniques" by way from "Line Survey Measurement" and "Compass Measurement" methods for determining the discontinuity characteristics of study surface before blasting for all of the realized blasting tests. Mm-division tape measure was used for being able to perform the line measurement. Vertical discontinuity range values were determined by line survey measurements while discontinuity plane angles of the blast surfaces were determined with compass measurements (Table 3). It was ensured that discontinuity characteristics of the blast surfaces are maintained constant by designing the blasts in the same direction in all of the blasting tests.

Segment thickness, distance between holes, hole diameter, explosive amount, hole length, and bench height values were measured in a very accurate manner for each blasting test as controllable parameters of the blasting. Technical parameters measured for blasting tests are given in Table 3.

TABLE 3

Controllable and uncontrollable values belonging to the blasting measured from working sites

Test no	a (°)	b (°)	c (cm/crack)	B (m)	S (m)	D (mm)	H (m)	Qe (kg)
Blasting tests carried out in Arkavadi 1st Region Quarry								
1	323	150	62.31	2.50	2.44	89	9.50	34.79
2	323	158	45.67	2.77	2.25	89	10.50	33.13
3	280	144	34.21	2.37	2.39	89	10.10	31.88
4	340	160	42.97	2.84	2.11	89	10.10	30.83
5	276	117	26.65	2.55	2.10	89	10.10	31.18
6	302	130	22.34	2.17	2.43	89	12.50	47.85
7	309	130	40.16	2.39	2.33	89	16.00	68.13
8	293	120	25.62	2.18	2.64	89	10.00	33.96
Blasting tests carried out in Arkavadi 2nd Region Quarry								
1	128	81	27.10	2.57	3.25	89	12.50	52.63
2	85	80	91.43	2.36	2.46	89	12.50	49.79
3	20	210	60.25	2.15	2.72	89	8.00	28.83
4	230	220	50.15	2.31	2.65	89	10.00	22.29

a = Slope direction angle belonging to stratification of the blast surface (°),
b = Slope direction angle belonging to blast surface (°),
c = Vertical discontinuity range (cm/crack),
B = Average segment thickness (m),
S = Average distance between the holes (m),
D = Hole diameter (mm),
H = Bench height (m),
Qe = Amount of explosive used per hole (kg).

2.3. Measurement of hydraulic oil pressures during the operation of the loader

It is known from the literature that the larger the average size value of the heap increases, the more the loader is forced. Front, back, arm closure, and bucket closure hydraulic pressure values occurred in hydraulic pistons of the loader and being the parameters determining whether the loader would be forced during loading of blasted material were measured in order to determine the correctness of average size values of the heap determined with Wipfrag image processing technique and were compared with average size values determined with Wipfrag image processing technique (Fig. 1).

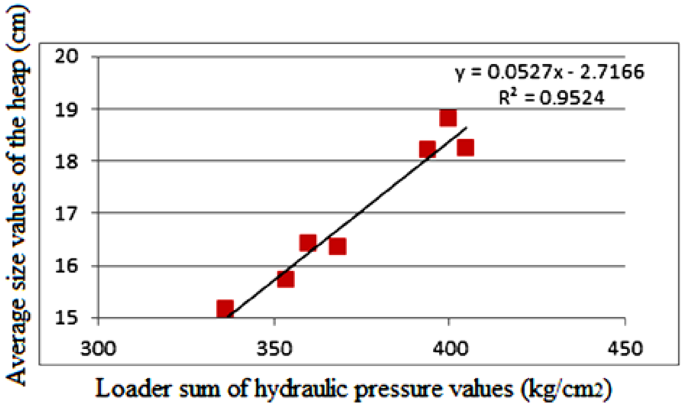

Fig. 1. Relation between loader average total hydraulic pressure values and average heap size values determined with Wipfrag image processing technique

In all blasting tests except for the first blasting test realized in the limestone quarry of Arkavadi 1st Region, instantaneous hydraulic pressure values in loader monitor during the loading of the material formed as a result of the blasting were measured with image processing technique (2012). Loader average hydraulic pressure values measured during the loading of all material formed as a result of blasting in blasting tests and approximative data numbers used in the obtainment of these average hydraulic pressure values are given in Table 4.

TABLE 4

Values measured for determining loader hydraulic pressure values in limestone quarry of Arkavadi 1st Region

	Loader Hydraulic Pressures (kg/cm²)							
Test no	**Front pump**	**Back pump**	**Arm closure**	**Bucket closure**	**Total**	**Total number of data (piece)**	**Average size value calculated with Wipfrag (cm)**	**Average size value calculated with correction Wipfrag (cm)**
1							21.01	16.73
2	192.46	185.83	12.09	14.67	405.04	138712	23.40	18.23
3	181.20	183.83	5.56	23.42	394.02	13812	24.62	18.19
4	189.24	193.02	9.74	8.09	400.10	12060	22.82	18.80
5	172.72	177.19	7.80	10.83	368.54	91048	23.52	16.34
6	161.10	160.85	4.83	9.42	336.21	146380	24.78	15.15
7	165.56	169.85	7.31	10.69	353.41	85828	21.20	15.73
8	169.82	176.69	5.53	8.10	360.14	59060	19.90	16.40

As is seen in Figure 1, a strong correlation relation of 95.24% is formed between heap average size value determined with Wipfrag image processing method and loader average total hydraulic pressure values. This situation shows that average size values of the heap are correctly determined with Wipfrag image processing method.

3. Evaluation

The results obtained from twelve blasting tests in total performed in this study were separately evaluated according to quarries of Arkavadi 1st Region and Arkavadi 2nd Region. Average granular size (D50) values belonging to each blasting test were calculated by using controllable parameters belonging to the blasting and rock factor values obtained from discontinuity measurements by using Kuz-Ram model. Obtained results and average size values of the heap determined with Wipfrag image processing technique are given in Table 5.

TABLE 5

Average size values of the heap calculated according to Kuz-Ram estimation model and determined with Wipfrag image processing technique

	Average size values of the heap (D50, cm)		
Test no	**Kuz-Ram estimation model**	**Wipfrag method**	**Difference %**
Blasting tests carried out in Arkavadi 1st Region Quarry			
1	26.61	16.73	37.12
2	30.35	18.23	39.94
3	27.86	18.19	34.72
4	29.78	18.80	36.88
5	27.09	16.34	39.66
6	24.15	15.15	37.26
7	24.57	15.73	35.98
8	27.30	16.40	39.93
Blasting tests carried out in Arkavadi 2nd Region Quarry			
1	25.10	16.08	35.94
2	25.15	16.95	32.60
3	23.84	14.53	39.05
4	27.06	17.13	36.69

As is seen from Table 5, average size values determined with WipFrag image processing technique occurred very differently from average size values calculated according to Kuz-Ram function due to discontinuity characteristics of blast surfaces. Therefore, average size values determined with WipFrag image processing technique were taken as reference point and land coefficient in the Kuz-Ram estimation model representing the discontinuity characteristics of Akravadi 1st Region blast.

When the relation proposed by Lilly and determining the rock factor is put in place in the Kuz-Ram model developed by Kuznetsov and determining average size value of the heap, the following relation is obtained.

$$X_{50} = 0,06\left(RMD + JF + RDI + HF\right)\left(\frac{V_o}{Q_e}\right)^{0.8} Q_e^{\frac{1}{6}}\left(\frac{S_{Anfo}}{115}\right)^{-\frac{19}{30}}$$

If $(RMD + JF + RDI + HF)$ is taken as M

$$\left(\frac{V_o}{Q_e}\right)^{0.8} Q_e^{\frac{1}{6}}\left(\frac{S_{Anfo}}{115}\right)^{-\frac{19}{30}} \text{ is taken as } N$$

It can be written as $X_{50} = 0.06MN$.

Blasts were performed always in the same direction so that the value M determining the discontinuity characteristics of the blast surfaces always have the same value in the blasting tests. Thus, correct determination of the land coefficient in Kuz-Ram estimation model determining the average size value of the heap was ensured.

TABLE 6

Data determining the land coefficient in Kuz-Ram estimation model

Test no	**Average size values determined with Wipfrag image processing technique (cm)**	***M***	***N***	***MXN***
1	16.73	146.10	2.96	432.63
2	18.23	146.10	3.38	493.52
3	18.19	146.10	3.10	453.06
4	18.8	146.10	3.31	484.31
5	16.34	146.10	3.01	440.36
6	15.15	146.10	2.69	392.65
7	15.73	146.10	2.73	399.50
8	16.40	146.10	3.04	443.95

As is also seen from Table 6, the values *MN* were calculated for each blasting test performed in Arkavadi 1st Region and a correlation relation was established between these values and average size values determined with Wipfrag image processing technique. The land coefficient was determined to be 0.0383 from obtained correlation relation equation (Fig. 2).

The new land coefficient in the Kuz-Ram estimation model was set to 0.0383 and the average size values of the heap were re-calculated according to the Kuz-Ram estimation model. These calculated values were compared with the average size values determined with Wipfrag image processing technique (Table 7 and Fig. 3).

Average size distribution values were calculated for blasting tests performed in Arkavadi 2nd Region by using the land coefficient of 0.0383 proposed in Kuz-Ram function. It is seen that these obtained values approached very close to average size distribution values determined according to Wipfrag method (Table 7 and Fig. 4).

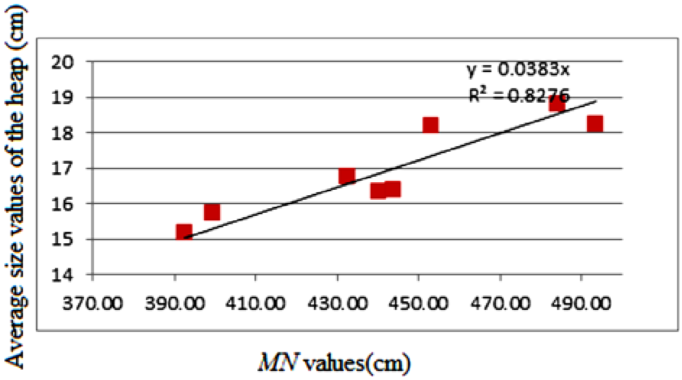

Fig. 2. Relation between average size values determined with Wipfrag image processing technique and the values *MN*

TABLE 7

Average size values of the heap calculated by using the land coefficient of 0.0383 in Kuz-Ram estimation model and determined with Wipfrag image processing technique

Test no	Average size values of the heap (D50, cm)		Difference %
	Kuz-Ram estimation model	Wipfrag method	
Blasting tests carried out in Arkavadi 1st Region Quarry			
1	16.57	16.73	0.96
2	18.90	18.23	3.69
3	17.35	18.19	4.61
4	18.55	18.8	1.33
5	16.87	16.34	3.22
6	15.04	15.15	0.74
7	15.30	15.73	2.73
8	17.00	16.40	3.68
Blasting tests carried out in Arkavadi 2nd Region Quarry			
1	15.63	16.08	2.79
2	15.66	16.95	7.60
3	14.85	14.53	2.18
4	16.85	17.13	1.62

4. Conclusion

In this research study, in order to correctly determine the land coefficient in Kuz-Ram estimation model used in the calculation of average size value of the heap occurring as a result of blasting, field tests have been carried out in two limestone quarries called as Arkavadi 1st Region and Arkavadi 2nd Region belonging to Western Anatolia Cement Plant (Batı Anadolu Cement Plant) located in Izmir, Turkey. Twelve blasting tests were carried out in total, eight in Arkavadi 1st Region quarry and four in Arkavadi 2nd Region quarry.

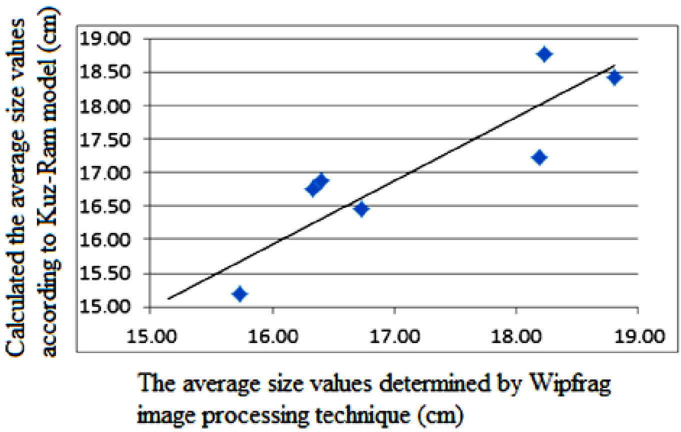

Fig. 3. Relation between average size values of the heap determined with Wipfrag image processing technique and proposed Kuz-Ram estimation model for blasting tests performed in Arkavadi 1st Region

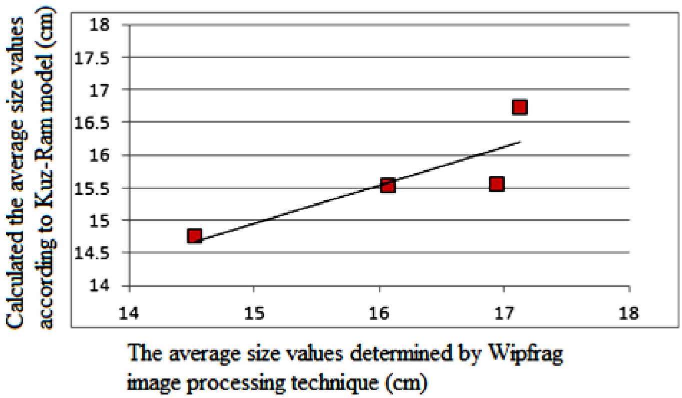

Fig. 4. Relation between average size values of the heap determined with Wipfrag image processing technique and proposed Kuz-Ram estimation model for blasting tests performed in Arkavadi 1st Region

It was ensured that discontinuity characteristics of the blast surfaces were maintained constant by performing the blasts always in the same direction and thus the land coefficient in Kuz-Ram estimation model is determined in a more correct manner.

Fragmentation degrees occurring as a result of blasting in all performed blasting tests were determined by using Wipfrag image processing method and Kuz-Ram estimation model.

It was ensured that very fine grains are also included in the calculation of average size distribution determined with Wipfrag image processing technique by using some different methods.

Correctness of average size values of the heap determined with Wipfrag image processing technique was proved with hydraulic pressure values formed in oil pumps of the loader during the loading of the blasted material.

Wipfrag analysis values of heap size distributions were very differently from those predicted the Kuz-Ram model due to structural characteristics of the rocks in the site. Therefore, average heap size distribution values calculated with the Kuz-Ram model do not reflect real values. The value 0.0383, a new land coefficient representing the structural characteristics of Arkavadi 1st Region limestone area, was determined so that the Kuz-Ram model can give improved results since each working area has different discontinuity characteristics and cracked fissured structure. The new land coefficient proposed for the Kuz-Ram estimation model was applied to blasting tests performed in Arkavadi 2nd Region and it was seen that the results approached very close to the results determined with Wipfrag method.

Acknowledgments

We wish to thank The Scientific and Technological Research Council of Turkey (TUBITAK) for providing funding for this research project and Western Anatolia Cement Factory for their help during field studies.

References

Bazzazı A.A., Esmaeılı M., 2012. *Prediction of backbreak in open pit blasting by adaptive neuro-fuzzy inference system.* Arch. Min. Sci., Vol. 57, No 4, p. 933-943.

Carlsson O., Nyberg L., 1983. *A method for estimation of fragment size distribution with automatic image processing.* In Proc. 1st International Symposium on Rock Fragmentation by Blasting, 333-345.

Cunningham C.V.B., 1983. *The Kuz-Ram model for prediction of fragmentation from blasting.* [In:] Proc. 1st Int. Symposium on Rock Fragmentation by Blasting, 439-453.

Cunningham C.V.B., 1987. *Fragmentation estimations and the Kuz-Ram model – four years on.* [In:] Proc. 2nd International Symposium on Rock Fragmentation by Blasting, 475-487.

Gheibie S., Aghababaei H., Hoseinie S.H., Pourrahimian Y., 2009. *Modified Kuz-Ram fragmentation model and its use at the Sungun Copper Mine.* International Journal of Rock Mechancs & Mining Sciences, 967-973.

Hudaverdi T., Kuzu C., Fisne A., 2012. *Investigation of the blast fragmentation using the mean fragment size and fragmentation index.* International Journal of Rock Mechanics & Mining Sciences, 136-145.

Kuznetsov V.M., 1973. *The mean diameter of the fragments formed by blasting rock.* Soviet Mining Science, 9(2), 144-148.

Lilly P.A., 1986. *An empirical method of assessing rock mass blastability.* [In:] Proc. Large Open Pit Mining Conference, 89-92.

Monjezı M., Ahmadı Z., Khandelwal M., 2012. *Application of neural networks for the prediction of rock fragmentation in chadormalu Iron mine.* Arch. Min. Sci., Vol. 57, No 3, p. 787-798.

Rosin P., Rammler E., 1933. *The laws governing the fineness of powdered coal.* J. Inst. Fuel, (7), 29-36.

Ouchterlony F., 2005. *The swebrec function linking fragmentation by blasting and crushing.* Inst. Min. Metall A., 114, A29-A44.

Tosun A., Konak, G., Karakuş D., Onur A.H., 2012. *Determination of loader efficiency with hydraulic pressure values.* International Multidisciplinary Scientific GeoConference SGEM, Bulgaria, 531-538.

Received: 05 February 2013