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HASSAN BAKHSHANDEH AMNIEH*, MOEIN BAHADORI*

SAFE VIBRATIONS OF SPILLING BASIN EXPLOSIONS AT "GOTVAND OLYA DAM" USING ARTIFICIAL NEURAL NETWORK

OKREŚLANIE BEZPIECZNEGO POZIOMU WIBRACJI W ZBIORNIKU TRAKCIE PRAC STRZAŁOWYCH PROWADZONYCH NA TAMIE GOTVAND OLYA Z WYKORZYSTANIEM SZTUCZNYCH SIECI NEURONOWYCH

Ground vibration is an undesirable outcome of an explosion which can have destructive effects on the surrounding environment and structures. Peak Particle Velocity (PPV) is a determining factor in evaluation of the damage caused by an explosion. To predict the ground vibration caused by blasting at the Gotvand Olya Dam (GOD) spilling basin, thirty 3-component records (totally 90) from 19 blasts were obtained using 3 VIBROLOC seismographs. Minimum and the maximum distance from the center of the exploding block to the recording station were set to be 11 and 244 meters, respectively. To evaluate allowable safe vibration and determining the permissible explosive charge weight, Artificial Neural Networks (ANN) was employed with Back Propagation (BP) and 3 hidden layers. The mean square error and the correlation coefficient of the network in this study were found to be 1.95 and 0.995, respectively, which compared to those obtained from the known empirical correlations, indicating substantially more accurate prediction. Considering the network high accuracy and precision in predicting vibrations caused by such blasting operations, the nearest distance from the center of the exploding block at this study was 11 m, and considering the standard allowable vibration of 120 mm/sec for heavy concrete structures, the maximum permissible explosive weight per delay was estimated to be 47.00 Kg. These results could be employed in subsequent safer blasting operation designs.

Keywords: Ground vibration, Safe explosion, Gotvand Olya Dam, Artificial Neural Network (ANN)

Wibracje gruntu to niepożądany skutek prowadzenia prac strzałowych, które mogą negatywnie wpływać na otaczające środowisko oraz znajdujące się w sąsiedztwie budowle. Głównym wskaźnikiem używanym przy określaniu szkód spowodowanych przez wybuchy jest wskaźnik maksymalnej prędkości cząstek (PPV). Przy prognozowaniu wibracji terenu wskutek prac strzałowych prowadzonych na tamie Gotvand Olya i w zbiorniku zbadano zapisy 3-składnikowych prędkości (w sumie 90 zapisów) z 13 wybuchów zarejestrowane przy użyciu sejsmografu 3 VIBROLOC. Maksymalna i minimalna odległość pomiędzy środkiem rozkruszanego bloku a stacją rejestrującą ustawiona została na poziomie 244 i 11 m. W celu określenia bezpiecznego poziomu drgań oraz dopuszczalnej wagi ładunku, zastosowano podejście

* DEPARTMENT OF MINING ENGINEERING, UNIVERSITY OF KASHAN, IRAN

wykorzystujące sieci neuronowe, z wykorzystaniem metody propagacji wstecznej i trzech warstw ukrytych. Błąd średniokwadratowy i współczynnik korelacji sieci wyniosły 1.95 i 0.95, co pozostaje w zgodności z danym uzyskiwanymi z obserwacji empirycznych, wskazując na poprawność i dokładność prognoz. Zakładając wysoki poziom dokładności sieci oraz wysoką dokładność w prognozowaniu poziomu drgań wywołanych przez prace strzałowe, przyjęto że najbliższa odległość od środka rozkruszanego bloku wyniesie 11 m. Uwzględniając standardowe dopuszczalne w przypadku ciężkich budowli betonowych poziomy drgań w wysokości 120 m/s, oszacowano że maksymalna dopuszczalna masa ładunku wyniesie 47.00 Kg, w przeliczeniu na jeden okres zwłoki. Wyniki badań wykorzystane być mogą w planowaniu kolejnych bezpiecznych prac strzałowych.

Słowa kluczowe: drgania gruntu, bezpieczeństwo prac strzałowych, tama Gotvand Olya, sztuczne sieci neuronowe

1. Introduction

Despite developments in technology and ever increasing progress in the modern machineries, drilling and blasting are common practice in many civil and mining engineering projects throughout the world due to their economic advantages and ease of operation and expertise required. In any explosion, a major part of the released energy is propagated in the form of waves causing damage to the surrounding environment and structures. Peak Particle Velocity (PPV) is the major criterion in the assessment of this type of damage. To foresee the PPV, many researchers have presented both experimental and numerical methods. Maximum weight of explosive per delay and the safe distance of the measuring point from the center of the exploding block are generally considered to be the main factors influencing the PPV in majority of these methods. However, experiences suggest that other factors such as the site geological and geotechnical conditions, exploding block geometry, explosive type and direction, burden and spacing, can also affect PPV.

In many research studies carried out in this regard since 1930, particle acceleration was found to be the main parameter in the prediction of probable damage to surface structures (Konya & Walter, 1985). The relationship between PPV the vibration damage caused by blasting operation was studied for the first time by Blair and Duvall (1954). They related the explosion vibration intensity, to the distance of the explosion site from the measuring station and also the amount of the explosive charge used. Hagan and Kennedy (1980) and later Mather (1984) investigated the relation between the explosive type and PPV. Other researches focused on the mitigation or elimination of damage and studied the influence of explosion delay time in this respect and consequently on the PPV. Blair and Jiang (1995) investigated the length of the explosive (from 0.45 to 5 m) and suggested that the horizontal component of the particle velocity is directly related to the explosive length for far distances. Roy (1998) presented different models, based on the mining operation type, to predict PPV and its destructive effects on surface structures. As mentioned earlier, PPV has been investigated in the majority of the above studies, as the main parameter in predicting ground vibration and the probable damage caused by the explosion. Since parameters affecting ground vibration intensity are numerous and their interactions remain vaguely defined to-date, experimental data results cannot be reliably employed for solving the ground vibration problems (Khandelwal & Singh, 2009).

As far as numerical methods are concerned, ANN, Genetic Algorithm (GA) and Neural-Fuzzy Technique (NFT) have been employed by several researchers to improve the accuracy of predicting the vibration. Singh et al. (2004) used ANN to predict the velocity of the longitudinal waves in anisotropic rock masses. Rao and Rao (2007) used NFT to predict the ground vibrations and frequencies caused by an explosion in an open pit mine. Khandelwal et al. (2005) and Khandelwal and Singh (2007 and 2009) made use of such effective factors as the rock type, blasting pattern, and explosive type (in addition to factors like the maximum weight of the explosive per delay and the distance between the measuring point and the center of the explosion block) as the input parameters to the ANN to determine the PPV and compared their results with those of similar methods available at the time. Bakhshandeh Amnieh et al. (2009), studied the effects of the number of blast holes rows on the PPV using the ANN. Bahadori et al. (2010) employed GA to improve the correlation coefficient for empirical relations used in the prediction of the PPV. Soltani et al. (2011) predicted the ground vibrations caused by blasting operations in Sarcheshmeh copper mine considering charge type, using ANFIS. Utilizing the SA Hybrid method, Soltani et al. (2012) also predicted the allowable charge weight per delay in blasting operations in construction of underground structures in Gotvand Olya Dam.

In this paper, the effects of the vibrations caused by blasting on the nearby concrete structures at GOD were studied by 3-dimensional seismographs. Using the scaled distance parameter, a relation was proposed to predict the PPV caused by an explosion; and finally, the permissible amount of the explosive to be used for the explosion was estimated. The results obtained here could be employed for safer design of the blasting operations required in completion of the dam.

2. Geological and geographical situation

GOD is the latest dam being constructed on Karoon river, at Khuzestan, south-west of Iran, 30 Km northwest of Shooshtar, and 12 Km from Gotvand (see Fig. 1). It is a rock fill dam with a clay core, having a crest of 760 m length, 15 m width and 180 m height with the storage volume of 4500 million m^3.

Fig. 1. Geographical position of Gotvand Olya Dam

The dam region consists of two main formations, namely; Bakhtiari and Aghajari (see Fig. 2). Petrologically speaking, Bakhtiari formation, having a height of 300 m, is made of conglomerate with a large thickness making the dam supports on both sides. Aghajari formation, on the other hand, is an alternate layering of mudstone, siltstone and sandstone with conglomerate layers. There are two main joint-systems and one irregular one in the structure of this formation, where the presence of discontinuity in the layering, along with the joint-systems and the formation's inherent low strength, caused difficulties in drilling operations.

The blast holes, (64 mm in diameter, 3 m in depth) were drilled with Tomrock (Ranger) and D7 boring machines using a 2 m × 2 m drilling pattern. Number of blast holes in each operation varied between 26 and 80 with one explosion being carried out each week. The explosives used were often ANFO being primed by Emulite. Pending on the rock type and explosion method, blast delay combinations of 0.5 second (HS1) to 5 seconds (HS10) were used.

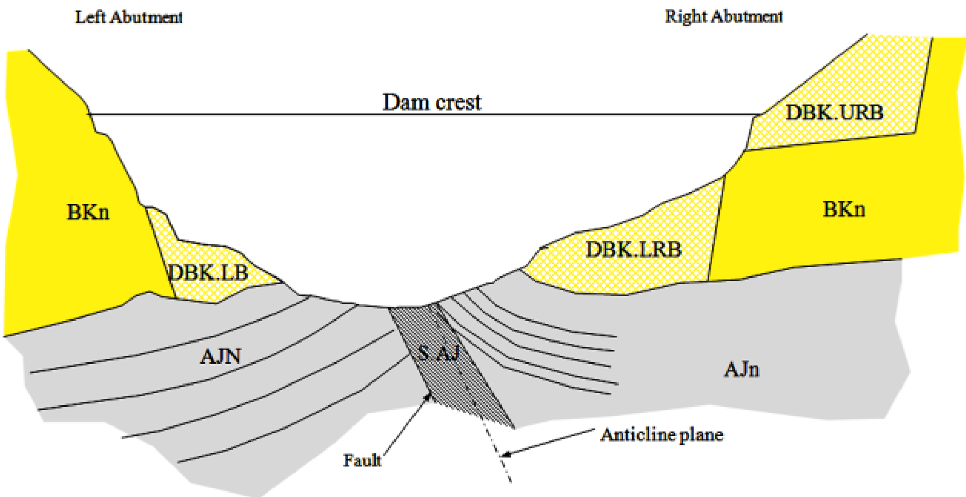

Fig. 2. Geological cross-section of Gotvand Olya dam
(AJN corresponds to Aghajari and BK corresponds to Bakhtiyari formations)

3. Research method

To study the effects of the vibrations, caused by blasting the spilling basin, on the dam spillway concrete structures, the records of 19 blasts were recorded and possessed. The VIBROLOC seismographs were mounted to record the vibration waves in a range of 120° radius. Table 1 shows the results of VIBROLOC seismograph.

For damage mitigation to the dam concrete structures, different standards are provided in industry considering the permissible PPV limit. In this work, PPV was determined using 'Association of African Explosives' standard (see Table 2). As can be seen, PPV is different for different structure conditions, for instance, a permissible PPV of 120 mm/sec is suggested for heavy concrete structures.

TABLE 1

VIBROLOC seismograph Data recordings at GOD blasting operations.

No.	d (m)	w (Kg)	PPV (mm/s)	No.	d (m)	w (Kg)	PPV (mm/s)
1	11.5	24.00	91.83	16	111.0	12.00	2.09
2	15.5	26.99	38.37	17	56.0	18.65	2.05
3	11.0	4.00	37.16	18	102.0	10.00	2.02
4	14.0	6.00	34.68	19	83.0	32.99	1.93
5	30.0	10.00	27.35	20	72.0	18.65	1.92
6	21.0	6.00	17.44	21	244.0	19.00	1.79
7	32.0	19.73	13.22	22	169.0	21.60	1.64
8	38.0	10.00	12.74	23	97.0	10.00	1.61
9	37.0	12.80	8.40	24	81.5	26.99	1.61
10	60.0	43.99	7.21	25	177.0	29.33	1.37
11	37.0	31.49	6.15	26	132.0	15.00	1.36
12	53.0	31.49	4.42	27	166.0	18.00	1.32
13	54.0	14.00	3.73	28	160.0	23.22	1.27
14	85.0	10.00	3.22	29	174.0	35.81	1.25
15	89.0	24.00	3.12	30	186.0	24.00	1.22

TABLE 2

PPV for different structure conditions (SABS, 1990)

Structure condition	PPV (mm/s)
Heavy concrete structures	120
Public properties (small cracks are negligible)	84
Personal properties under repair and places not under severe public supervision	50
Personal properties and places under severe supervision for explosion vibrations	10

4. Empirical relations

Oriard (1980) proposed the following empirical relation (Eq. 1) based on PPV having a direct relation with the charge weight, and inverse relation to the distance between the measuring station and the explosion site

$$PPV = a\left(d / \sqrt{w}\right)^{-b} \tag{1}$$

where d is the distance from the measuring point to the center of the explosion block (m), w is the maximum weight of the explosive per delay (Kg) and the expression $Sd = d / \sqrt{w}$ is the scaled distance (m/Kg$^{1/2}$). Also, ‘a’ and ‘b’ are constants depending on the geological parameters of the site. Figure 3 shows how PPV changed with respect to the scaled distance for vibrations caused by explosions in the GOD spilling basin.

Figure 3, demonstrates that ‘a’ and ‘b’, i.e. Gotvand site constant parameters were 205.7 and -1.40, respectively. Considering the geological and geomechanical characteristics of GOD, Mojtabai and Beatty (1995) empirical relationship proposed for sedimentary rock mass, Eq. (2), was also used in this study, where d and w are the same parameter as those of Eq. (1).

$$PPV = 161.9 \times \left(\frac{d}{\sqrt{w}} \right)^{-1.327} \tag{2}$$

As can be seen from Figure 4, correlation coefficient for the measured and predicted values in this relationship is 0.863.

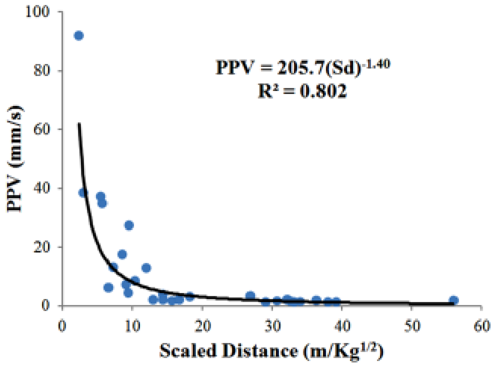

Fig. 3. PPV versus scaled distance for Gotvand Olya Dam

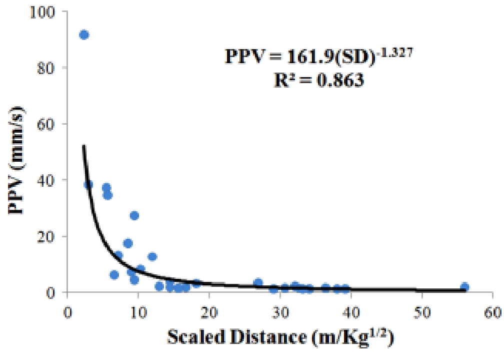

Fig. 4. Predicted values of PPV using Mojtabai & Beatty empirical relation for GOD

5. Artificial Neural Networks (ANN)

ANNs are made of simple elements called neurons that operate parallel to one another; the human nervous system has been the source of inspiration to these elements and their relations determine the network operation. The network is tested for a specific purpose by modifying these relations (weights). The current networks are modified or trained so that a specific input leads to a specific output. During the training process, the network is modified on the basis of the comparison between the real and the network outputs until an acceptable error is achieved. One of the methods of network training is using the Back Propagation (BP) algorithm. The basic vector network, sigmoidal layers and linear output layer, is capable of estimating any activity with a limited number of discontinuities. There are two computational routes in the BP algorithm; the first is the 'force feed' or 'depart', where the network parameters do not change when the 'depart' calculations are carried out and, in addition, the stimulating functions operate on the neurons individually. The second is the 'back feed' or 'return' where the sensitivity vectors return from the last layer to the first. In the 'return' route, the work starts from where the error vector is available (the last or the output layer). Then, the local gradient is calculated with the return algorithm, neuron by neuron, from the last layer to the first. Finally, it is modified considering the weights training algorithm and each layer's bias (Lilly, 1986). Effort has been made in this study to suggest the maximum explosive weight per delay for the explosion of Gotvand Olya spilling basin using the artificial neural network (ANN) for a nearest distance of 11m from the explosion site and a vibration standard of 120 mm/sec for the spillway heavy concrete structures. The preliminary data were divided into three groups for training (20 sets), validation (4 sets) and testing purposes (the rest).

5.1. Network training

To do the neural network training, considering the limited number of data available, use has been made of 20 recordings from the explosions of Gotvand Olya Dam spillway mine. The data have been generated from 19 blasting operations in the dam spilling basin. The network inputs are the distance (in meters) between the center of the exploding block and the measuring point; and, the maximum explosive weight (in kilograms per delay). The output is the vibration (in mm/sec) produced by the explosion. The training network consists of 3 hidden layers and a single output layer having an array of {1, 5, 7 and 12} respectively; the BP algorithm has been used for network training purposes. Hidden layers stimulating functions are of the sigmoidal tangent type being able to scale the network in an interval of [–1,1]. A schematic view of the BP artificial neural network that used in this paper is shown in Figure 5. As seen, two input parameters are the charge weight per delay and the distance from the blast point and there is 1 neuron that calculated the PPV associated with this input data in the output layer. Furthermore, there are 3 hidden layer and the number of neurons in these layers are 12, 7 and 5, respectively (see Fig. 5). The estimation in question was carried out in the Neurosolution 6 software; and, to compare the error between the real and the predicted network data, mean square error operation function was used, which controls the network training at the end of each round through the calculation of the error. Using this function, the final error of the network training was reduced to 3.9e-28. Figure 6 shows the training mean square error as a function of the model iterations number. As shown, the mean square error of the cross validation data decreased with an increase in the number of iterations which indicates the effect of the number of iterations on the capability of the network learning – hence the successful training of the model. This network is capable of learning the relation between the input and the output parameters quite satisfactorily.

Layer Name	Input	Hiden Layer 1	Hiden Layer 2	Hiden Layer 3	Outout
Number of Neurons	2	12	7	5	1

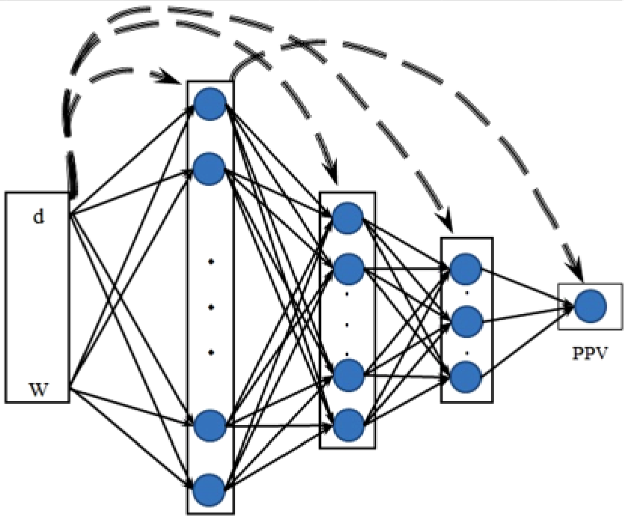

Fig. 5. Schematic view of Back Propagation Neural Network with 3 hidden layers

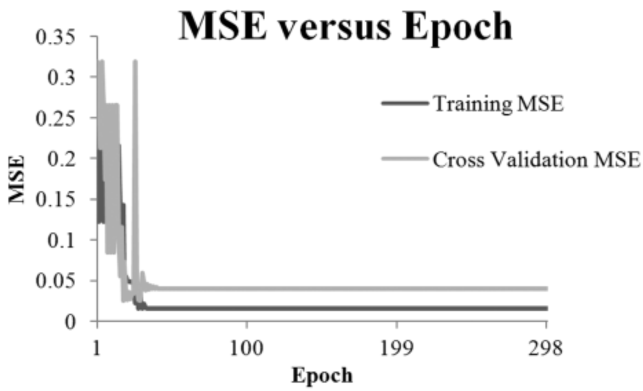

Fig. 6. Training and cross validation mean square error versus the number of iterations

To insure the accuracy of training, the network was tested with 6 series of vibration data generated from the explosions. Figure 7 illustrates the conformity between the real data and those predicted by the network with a correlation coefficient of 0.994 and a mean square error of 1.95.

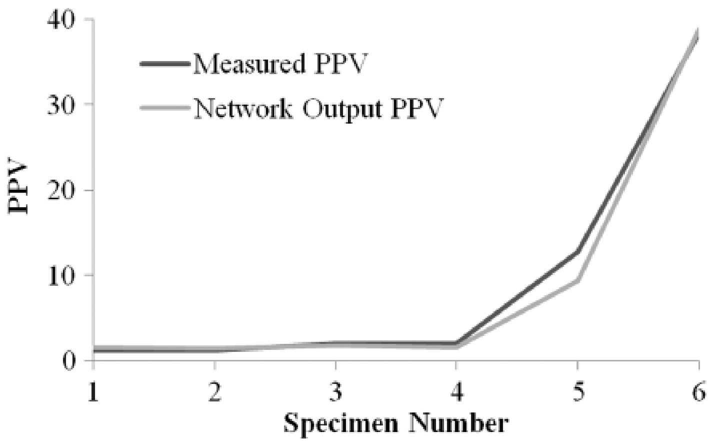

Fig. 7. Conformity between measured and predicted PPVs using ANN

6. Comparison of the empirical relations outputs with those of the ANN

Now, considering the high accuracy and precision of the network in estimating PPVs obtained from blasting operations of the dam spilling basin despite the limited number of data available for training and validation in this study, the outputs of the empirical relations proposed by Oriard (1980) and Mojtabai & Beatty (1995) have been compared with those of the network. In table 3, the results of the neural network outputs and those of the empirical relations expressed in equations 1 and 2 have been shown for 6 sets of data and the prediction errors for both methods have been found from relation 3 below:

$$error = \left(PPV_{actual} - PPV_{predicted}\right) / PPV_{actual} \tag{3}$$

TABLE 3

Comparing the results of empirical relations and those predicted by ANN

Distance from the explosion point (m)	160.0	166.0	102.0	111.0	38.0	15.5
Maximum explosive weight per delay (Kg)	23.22	18.00	10.00	12.00	10.00	26.99
Measured PPV	1.27	1.32	2.02	2.09	12.74	38.37
Predicted PPV (ANN)	1.40	1.26	1.83	1.77	9.41	38.82
Network predicting error	–0.102	0.045	0.094	0.153	0.261	–0.012
Predicted PPV [Oriard (1980)]	1.526	1.213	1.589	1.604	6.332	44.527
Error associated with Oriard (1980) relation	–0.202	0.081	0.213	0.233	0.503	–0.160
Predicted PPV [Mojtabai and Beatty (1995)]	1.551	1.247	1.612	1.626	5.975	37.957
Error associated with Mojtabai and Beatty (1995) relation	–0.221	0.055	0.202	0.222	0.531	0.012

As shown in Table 3, PPV predicted by ANN is more accurate. Almost in all cases reported, the mean square error (MSE) is less than those obtained by Oriard (1980) and Mojtabai & Beatty (1995) empirical correlations. This confirms the accuracy of the training process. Based on these data and a standard vibration of 120 mm/sec for Gotvand Olya Dam spillway concrete structures, and also for a nearest distance of 11 m from the center of the exploding block, the weight of explosive per delay was estimated to be 47.00 Kg.

7. Conclusions

Considering the processing of the records taken from the explosion of Gotvand Olya Dam spilling basin, both Oriard and Mojtabai & Beatty empirical relations for the prediction of probable damage to the construction site of this dam were formulated in a negative exponential form with a correlation coefficient of 0.802 and 0.863, respectively. Using the back propagation ANN with three hidden layers, a MSE of 1.95 and a correlation coefficient of 0.995 (during the test), the PPVs for 6 sets of explosion vibration records were predicted and the results were compared with those obtained from empirical relations. Considering the precision of the trained network for a nearest distance of 11 m (to the explosion block) and an allowable PPV limit of 120 mm/sec for Gotvand Olya dam spillway concrete structures, the maximum allowable weight of the explosive per delay was found to be 47.00 Kg, this is estimated for both Oriard and Mojtabai & Beatty empirical relations to be 56 Kg and 78 Kg, respectively. The lesser charge weight predicted by ANN implies safer operation and less damage to the structure.

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