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INVESTIGATING GROUND VIBRATION TO CALCULATE THE PERMISSIBLE CHARGE WEIGHT FOR BLASTING OPERATIONS OF GOTVAND-OLYA DAM UNDERGROUND STRUCTURES

BADANIA DRGAŃ GRUNTU W CELU OKREŚLENIA DOPUSZCZALNEGO CIĘŻARU ŁADUNKU WYBUCHOWEGO PRZY PRACACH STRZAŁOWYCH W PODZIEMNYCH ELEMENTACH TAMY W GOTVAND-OLYA

Ground vibration, air vibration, fly rock, undesirable displacement and fragmentation are some inevitable side effects of blasting operations that can cause serious damage to the surrounding environment. Peak Particle Velocity (PPV) is the main criterion in the assessment of the amount of damage caused by ground vibration. There are different standards for the determination of the safe level of the PPV. To calculate the permissible amount of the explosive to control the damage to the underground structures of Gotvand Olya dam, use was made of sixteen 3-component (totally 48) records generated from 4 blasts. These operations were recorded in 3 directions (radial, transverse and vertical) by four PG-2002 seismographs having GS-11D 3-component seismometers and the records were analyzed with the help of the DADISP software. To predict the PPV, use was made of the scaled distance and the Simulated Annealing (SA) hybrid methods. Using the scaled distance resulted in a relation for the prediction of the PPV; the precision of the relation was then increased to 0.94 with the help of the SA hybrid method. Relying on the high correlation of this relation and considering a minimum distance of 56.2 m to the center of the blast site and a permissible PPV of 178 mm/s (for a 2-day old concrete), the maximum charge weight per delay came out to be 212 Kg.

Keywords: Blasting, Ground Vibration, Peak Particle Velocity, Simulated annealing algorithm

Drgania gruntu, rozchodzenie się drgań w powietrzu, rozrzut skał, ich niepożądane przemieszczenia i rozdrobnienie to nieuchronne skutki prowadzenia prac strzałowych, które spowodować mogą poważne spustoszenie w środowisku naturalnym. Maksymalna prędkość drgań cząstek (PPV) to główne kryterium przy ocenie szkód spowodowanych przez drgania podłoża. Istnieje wiele norm określających bezpieczne poziomy prędkości drgań cząstek (PPV). Obliczenie dopuszczalnej wielkości ładunku wybuchowego w taki sposób, by zapobiegać uszkodzeniom podziemnych elementów tamy Gotvand Olya opiera się na

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wykorzystaniu 16 3-elementowych zestawów danych zarejestrowanych w trakcie 4 wybuchów. Procedura rejestracji obejmuje zapisy drgań w 3 kierunkach (promieniowe, poprzeczne i pionowe) zarejestrowane przez 4 sejsmografy wyposażone w sejsmometry GS-11D, zaś same zapisy analizowano przy wykorzystaniu oprogramowania DADISP. Przewidywanie prędkości drgań cząstek odbywa się w oparciu o skalowanie odległości oraz metody hybrydowe Simulated Annealing (S.A.). W wyniku skalowania odległości otrzymujemy wzorów na prędkość drgań cząstek, przy wykorzystaniu metod hybrydowych dokładność obliczeń wzrasta do 0.94. Wykorzystując wysoki stopień korelacji wynikający ze wzoru, uwzględniając minimalną odległość 56.2 m od epicentrum wybuchu oraz dozwolony poziom prędkości drgań cząstek gruntu 178 mm/s (dla dwudniowego betonu), otrzymujemy maksymalną wielkość ładunku na pojedynczy wystrzał na poziomie 212 Kg.

Słowa kluczowe: prace strzałowe, drgania podłoża, maksymalną prędkość drgań cząstek (PPV), algorytm hybrydowy

1. Introduction

Despite fast progress in technology and manufacturing of huge and flexible machinery, drilling and blasting are still used widely in civil and mining operations. Since blasting is a time consuming activity in a tunnel construction cycle, it not only delays the project finishing time, but also increases the construction costs; the delay can even question the project economic justification. Diminishing the drilling and blasting time (and then installing the supporting system) is a means of reducing the tunnel construction costs. Tunnel excavation, with a blasting operation, releases a huge amount of energy in a very short time which is usually accompanied by the generation and propagation of impact waves in the surrounding environment. Since wave propagation may cause destruction of the structures, it is necessary that the dynamic forces, caused by blasting, be predicted and controlled; this is possible by controlling the specifications of the propagated waves. Finding reliable and standard amount of explosives, to avoid damage to subsurface structures, such as caverns, fuel storage tanks, water diversion and transfer tunnels, is a necessity. Generally, damage to tunnel concrete structures, due to blasting operations, is directly related to two elements, namely ground vibration and fly rock. There has been much research regarding the prediction and control of ground vibration caused by blasting operations since 1930 (U.S. Army Corps of Engineers, 1972, 1995, 1997; Olofsson, 1998; Duval & Atchison, 1959; Langefors & Kihlstrom, 1978; Oriard, 1980; Hagan & Kennedy, 1980; Mather, 1984; Blair & Jiang, 1995; Rock blasting technique, 1998; Hashash et al., 2001; Lucca & Terra, 2003). In many of such researches PPV has been considered the main parameter in predicting the amount of ground vibration and the probable damage caused by blasting.

A method used nowadays in open and subsurface blasting operations is to plan the operation based on PPV at specified distance (U.S. Army Corps of Engineers, 1997; Olofsson, 1998). To predict the PPV, researchers have presented different methods that are grouped into two general classes: empirical and numerical. Empirical methods offer some standards to avoid damage to nearby structures in the blasting area. Duval and Atchison (1959) have proposed permissible PPVs of 2000 and 760 mm/s to control the probable damage to tunnels excavated in granite and sandstone rock masses respectively (Duval & Atchison, 1959). The U.S. Army Corps of Engineers (1972, 1995) has proposed the allowable amount of this factor for rock walls of underground structures to be 500 mm/s (U.S. Army Corps of Engineers, 1972, 1995). Longfors and kihlstorm (1978) have proposed a PPV equal to 610 mm/s for new cracks to appear in subsurface structures (Langefors & Kihlstrom, 1978). An important factor in using blasting for tunnel excavation is to be able to control the probable damage to concrete structures and the supporting system erected at a specified distance from the blast site. To predict probable damage to tunnel structures it is possible to define the PPV in the form of a function of the concrete intrinsic properties and its shear and tension strengths. On this basis, Oriard (1980) proposed a permissible PPV of 2540 mm/s after studying the fractures occurred in concrete (Oriard, 1980). Hagan and Kennedy (1980) and Mather (1984) investigated the relation between particle velocity due to blasting and the type of used explosive (Hagan & Kennedy, 1980; Mather, 1984). Blair and Jiang (1995) concentrated their studies on the explosive charge lengths between 0.45 m and 5 m and found out that, at far distances, peak particle horizontal velocity is directly related to the charge length (Blair & Jiang, 1995). The intensity of the vibration in the ground will depend on physical and geological properties of the rock mass, distance from the source that create the vibration, the amount of charge used and the specifications of the vibration source (Rock blasting technique, 1998; Hashash et al., 2001; Lucca & Terra, 2003).

In numerical methods, use is made of such tools as Artificial Neural Networks (ANN), Genetic Algorithm (GA), Support vector machine (SVM) and Neuro-Fussy techniques (NFT). Singh et al. (2004) have used the ANN to predict P-Wave velocity in anisotropic rock masses (Singh et al., 2004) . Khandelwal et al. (2005) and Khandelwal and Singh (2007, 2009) used other effective factors like the type of rock mass, blasting pattern, characteristics of the charge, … (in addition to maximum charge weight per delay and distance from the measuring point to the center of the blast site) to predict the PPV and compared the results with those of the similar methods (Khandelwal et al., 2005; Khandelwal & Singh, 2007, 2009). Although experience has proved that other parameters like geological and geotechnical conditions of the area, geometry of the explosion site, type of the charge used, direction of explosion and … too affect the PPV, the empirical methods have not been successful because the number of effectual parameters is too high and the inter-relation among them is also very complicated (Khandelwal et al., 2005). Rao and Rao (2007) have made use of the NFT to predict ground vibration and its frequency caused by blasting in an open pit mine (Rao & Rao, 2009). Bakhshandeh Amnieh et al. (2009) have studied the effect of the number of blast rows on the PPV using the ANN (Bakhshandeh Amnieh et al., 2009). Bahadori and Bakhshandeh Amnieh (2010) have used the GA to enhance the regression of the empirical relations used in the prediction of the PPV caused by blasting operations in Sarcheshmeh copper mine, Kerman, Iran (Bahadori & Bakhshandeh Amnieh, 2010). Azimi et al. (2010) have suggested new empirical relation for predicting PPV based on the recorded ground vibrations from the blasting operation at the Sungun Copper mine (Azimi et al., 2010). Soltani Muhammadi et al. (2011) have used the Adaptive Neuro-Fuzzy networks, to investigating of the effect of the type of charge used on ground vibration caused by blasting operation in Sarcheshmeh copper mine (Soltatni et al., 2011). In this study, to increase the conformity between the measured and the predicted data of the vibration caused by blasting, the optimum constants of Gotvand Olya dam site were determined. Considering the detrimental effects of vibration on the strength properties of structures, and to optimize their resulting behavior when they experience vibrations, controlling the amount of vibration caused by blasting is a method for the mitigation of the destructive effects. Here, the specifications of the destructive waves are found through numerical modeling and empirical methods and, on this basis, the amount of permissible charge weight per delay is determined.

In this paper, to study the effects of blasting operation on the intact and surge tanks of Gotvand Olya dam on the subsurface concrete structures, sixteen 3-component (totally 48) records from 4 blasts were recorded. These operations were recorded with four PG-2002 seismographs having

GS-11D 3-component seismometers in three vertical, radial and transverse directions and then analyzed with the help of the DADISP software. Using the scaled distance parameter, a relation was proposed for the determination of the PPV caused by blasting and, finally, the amount of permissible charge weight for blasting at the intact and surge tanks of Gotvand Olya dam was estimated with the help of the Simulated Annealing algorithm.

2. Data used

Gotvand Olya dam, in Khuzestan province, Iran, is located at 30 km nort-hwest of the shushtar city, 12 Km from Gotvand city (Figure 1) and is the latest dam built on Karoon river. The dam body is of the spalling type with a clayey core; crown length is 760 m and the width is 15 m; the dam height is 180 m (from the foundation) and its storage capacity is 4500 million cubic meter.

Fig. 1. Geographical location of and the access ways to Gotvand Olya dam

Geology of Gotvand Olya dam consists of two main formations: Bakhtiary and Aghajary. In general, from lithological point of view, Bakhtiary formation, made of very thick conglomerate, constitutes the dam foundations at the two sides with a height of 300 m. Aghajary formation, on the other hand, has an alternate layering of mudstone, sandstone and conglomerate. Structurally speaking, there exist two main joint-sets and one set of unsystematic joint in this formation. Presence of discontinuity in the bedding planes, along with the joint sets and the inherent low strength, has caused drilling to be difficult in this formation. The dam water supply tunnels and the surge tanks are situated at the left side which is in Bakhtiary formation. To find the allowable PPV values, use has been made of the table proposed by the U.S. Army Corps of Engineers (1995). According to this table, PPV is a function of time after concrete pour. Table 1 shows the allowable PPV with respect to time after pour proposed by the U.S. Army Corps of Engineers (U.S. Army Corps of Engineers. 1995).

TABLE 1

Allowable PPV with respect to time after concrete pour based on the US Army Corps of Engineers (U.S. Army Corps of Engineers. 1995)

Time after pour (hour)	PPV (mm/s)	PPV (ips)
Less than 3	102	4
Between 3 to 11	38	1.5
Between 11 to 24	51	2
Between 24 to 48	102	4
More than 48	178	7

There have been four blasting operations in this area where the maximum weight of explosive used per delay in the intact and the surge tanks were in the range of 32 to 343.3 Kg with mostly ANFO and Dynamite being the explosives. To study the effects of the vibrations caused by blasting operations on the concrete structures of the water supply tunnels, shaft and tanks of Gotvand Olya dam, a total of four seismographs were mounted at distances from 56.2 to 145.5 m, measured from the center of the blast site; PPV was selected as a criterion for this study. To do this, sixteen 3-component (totally 48) records were recorded. Recording was carried out by four PG-2002 seismographs with GS-11D 3-component seismometers in three vertical, radial and transverse directions and the data were analyzed with the help of DADISP software.

3. Factors affecting the amount of ground vibration

The maximum charge weight per delay is one of the most important factors affecting the blast vibration. Figure 2 shows PPV versus charge weight per delay. As shown, there is a non-linear relation among the data.

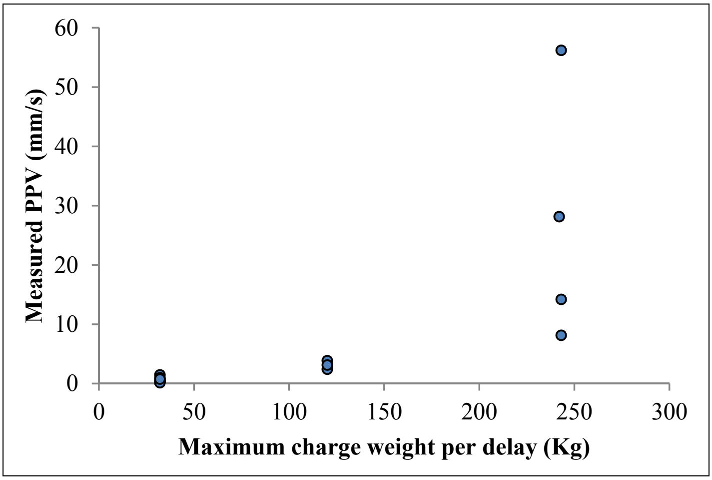

Fig. 2. PPV values versus charge maximum weight per delay in blasting operations of the Gotvand Olya Dam

Another parameter affecting ground vibration is the distance from the blast site. It is possible, in general, to accept equation (1) between the particle velocity and the distance from the blast site (Konya & Walter, 1985; Pal Roy, 1998):

$$V \alpha \frac{1}{d^b} \tag{1}$$

where *V* is the particle velocity, *d* is the distance from the blast site and *b* is a constant related to the blast site. Figure 3 shows PPV versus the distance from the blast site. As shown, PPV decreases exponentially with an increase in the distance.

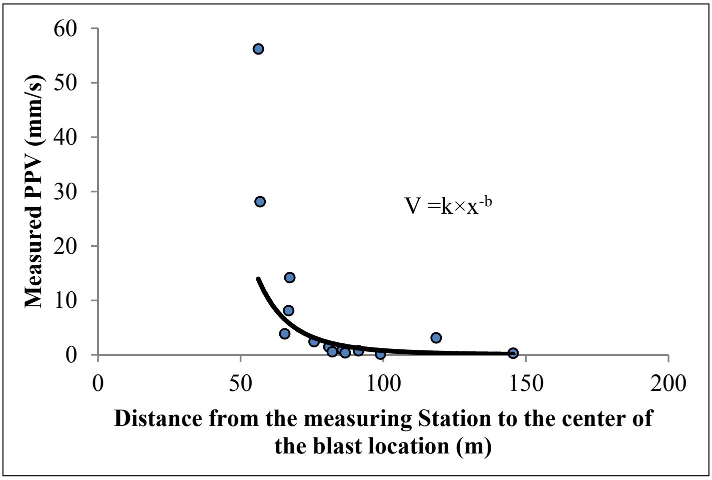

Fig. 3. PPV values versus the distance between the measuring station and the center of the blast site

4. Research method

4.1. Predicting vibration caused by blasting using empirical methods

After processing the data gathered from the blasts, to find a general relation for the determination of PPV, use was made of the Excel software for the statistical analysis of the recorded data. Based on the third root of the scaled distance, the empirical relation of the probable damage to the site of this dam is as follows:

$$PPV = 20339\ Sd^{-3.08} \tag{2}$$

where *PPV* is the Peak Particle velocity (mm/s) and *Sd* is the scaled distance m/Kg$^{1/3}$ (the ratio between the distance of the measuring station from the center of the blast site (m) and the third root of the maximum charge weight per delay (Kg)). The constants of Gotvand Olya dam site were measured to be 20339 and –3.08. This is a negative exponential function with a correlation coefficient of 0.9. Figure 4 shows an empirical graph of PPV versus the scaled distance in Gotvand Olya dam.

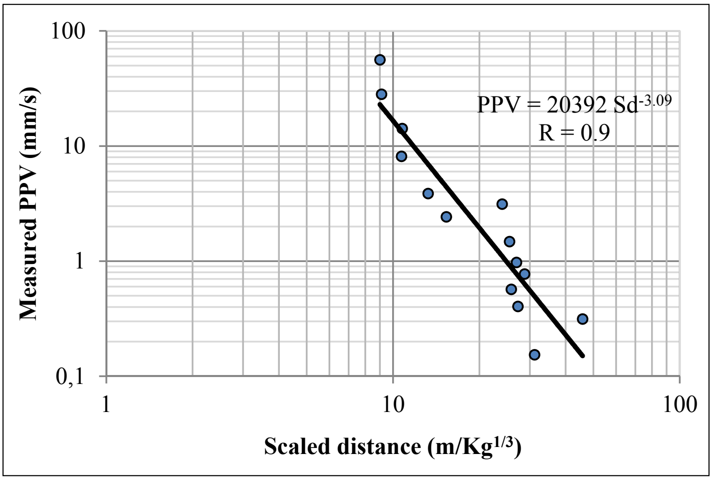

Fig. 4. PPV values versus scaled distance in Gotvand Olya dam

5. Predicting PPV using Simulated Annealing algorithm

As mentioned before, the charge weight per delay and the distance between the measuring station and the center of the blast site are two important factors affecting vibrations caused by blasting operations (Jimeno et al., 1995). The intensity of vibration is directly related to the charge weight and inversely to the distance from the blast site. Hence, vibration can be shown in the form of a function relating the charge weight (*w*) and the distance from the block center (*d*) as follows:

$$PPV = b\left(\frac{d}{w^n}\right)^a \tag{3}$$

where *a*, *b* and *n* vary with the blast condition and have to be determined. In this paper, effort has been made, using the SA optimization algorithm, to determine them in such a way that there is the most conformity between the measured and the predicted values for blasting operations in Gotvand Olya dam site. To use this algorithm, it is necessary that the objective function, preliminary values of *a*, *b* and *n*, movement generator, preliminary temperature and the cooling trend be defined first.

a) Defining the objective function

The objective is to find *PPV* values considering the maximum charge weight per delay and the distance from the blast site in such a way that the correlation coefficient between the predicted and measured values is maximized. Since the correlation coefficient r is a parameter that shows the precision of the output function, it can be used as the objective function; the optimization problem, then, may be stated as:

Maximize *r*

Correlation coefficient of exponential functions is found from the following equation (Jimeno et al., 1995):

$$r=\frac{\left(\left(\sum_{i=1}^{m}\left((\log PPV_E(i))\times(\log PPV_M(i))\right)\right)-\left(\left(\sum_{i=1}^{m}\log PPV_E(i)\right)\times\left(\sum_{i=1}^{m}\log PPV_M(i)\right)\Big/ m\right)\right)^2}{\left(\left(\sum_{i=1}^{m}(\log PPV_E(i))^2\right)-\frac{\left(\sum_{i=1}^{m}\log PPV_E(i)\right)^2}{m}\right)\times\left(\left(\sum_{i=1}^{m}(\log PPV_M(i))^2\right)-\frac{\left(\sum_{i=1}^{m}\log PPV_M(i)\right)^2}{m}\right)} \quad (4)$$

where m is the number of the recorded data, $PPV_M\ (i)$ is the measured peak particle velocity at point i and $PPV_E\ (i)$ is the estimated peak particle velocity at point i. The PPV_E at different points is a functions of coefficients a, b and n.

b) Decision variables

Coefficients a, b and n are the decision variables or the unknown parameters in the objective function.

6. Using SA algorithm for problem solving

The objective is to find coefficients a, b and n in such a way that the correlation coefficient between the predicted and the measured values is maximized. Considering the recorded ground vibration data and those predicted from equation (3), the correlation coefficient between these two sets of data can be calculated from equation (4). This is possible through iterations and selection of different values and combining them in a logical range. Practically, the number of these combinations is very large and, hence, the possibility of thorough and comprehensive search among all possible combinations is out of the question. In such cases, use has to be made of efficient search algorithms instead of a comprehensive search.

Simulated annealing is an iterative, combinatorial optimization algorithm in which a sequence of combinations is generated by deriving a new combination from the slightly and randomly changed the previous combination (Retrieved from Structures; Aarts & Korst, 1989; Van Gorenigen & Stein, 1999; Van Groenigen et al., 1999). This algorithm consists of two basic mechanisms: generating alternatives and acceptance rule (Lee & Elsharkawi, 2006). After each new combination is generated, the objective function (e.g. correlation coefficient) is calculated and compared with the previous one. If the value of the objective function has been improved, this combination is accepted. To avoid being trapped in a local optimum, the algorithm may accept some of the combinations that worsen the objective function. The probability of the acceptance of such a worse combination is given by:

$$P = e^{-\frac{\Delta f}{T}} \tag{5}$$

where Δf is the amount of change in the objective function and T is a controlling parameter known as the system temperature which gradually decreases during the optimization process. According to equation (5), with an increase in the value of the objective function (when minimization is the objective), the acceptable probability of its related combination decreases. In this process, the system temperature remains unchanged for a particular number of iterations and then decreases. This causes the acceptance probability to decrease gradually and simultaneously with the sequence of the iterations (for equal Δfs).

In this research use has been made of the simulated annealing method to search for the optimized coefficients *a*, *b* and *n* in equation (3). MATLAB R2010b software is able to do simulated searching, but for this purpose, the objective function of the problem has to be defined as an M-file and, moreover, the initial temperature parameters, cooling schedule and generation mechanism too have to be determined. Figure 5 shows the convergence trend during optimization process.

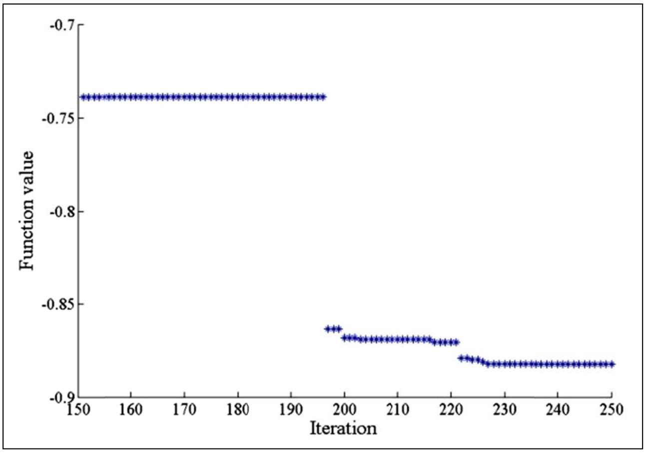

Fig. 5. The objective function value vs. the number of iterations

Optimization by SA algorithm (for the determination of the constant values a, b and n in equation (3)) resulted in –1.84, 19.11 and 0.745 respectively; the value of the correlation coefficient of the exponential function based on these constants generated was found to be 0.94. Figure 6 compares the results of the estimation of vibration caused by blasting in the intact and surge tanks of Gotvand Olya dam using the SA algorithm and empirical equation (2). As shown, using the SA algorithm enhances the correlation coefficient from 0.9 to 0.94.

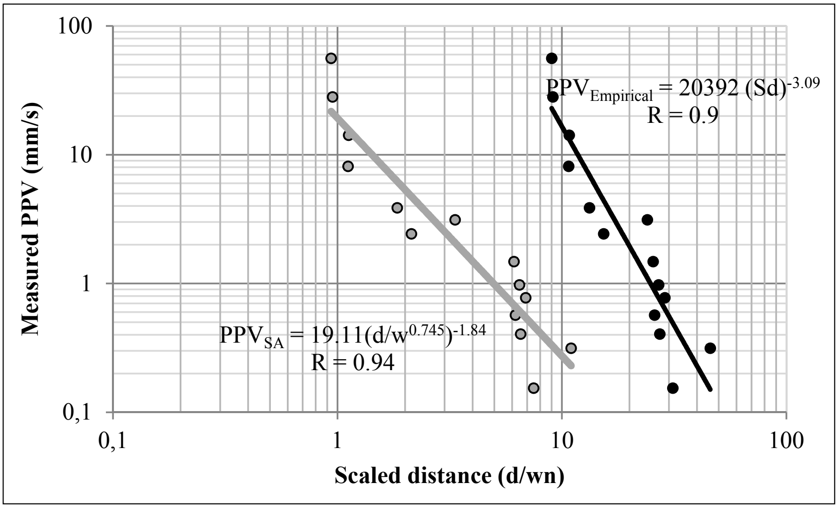

Fig. 6. Comparison of the prediction of Gotvand Olya dam substructures vibrations using the SA algorithm and empirical equations

7. Conclusions

Considering the analysis of the data generated in Gotvand Olya dam blasts, the predominante frequencies came out to be from 1.1 to 47.5 Hz. The empirical relation for prediction of the probable damage to Gotvand Olya dam site was found to be in a negative exponential form with a correlation coefficient of 0.9; this coefficient was enhanced to 0.94 using the SA algorithm. The area constants were found by the SA algorithm. Relying on the high precision of the proposed relation for the prediction of PPV, it is possible to find the maximum permissible charge weight per delay based on the distance from the blast site to the structure in question and the age of the concrete. In this research, with a least d = 52.6 m, a permissible PPV = 178 mm/s and a 2-day old concrete, the maximum permissible charge weight per delay was found to be 212 Kg.

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