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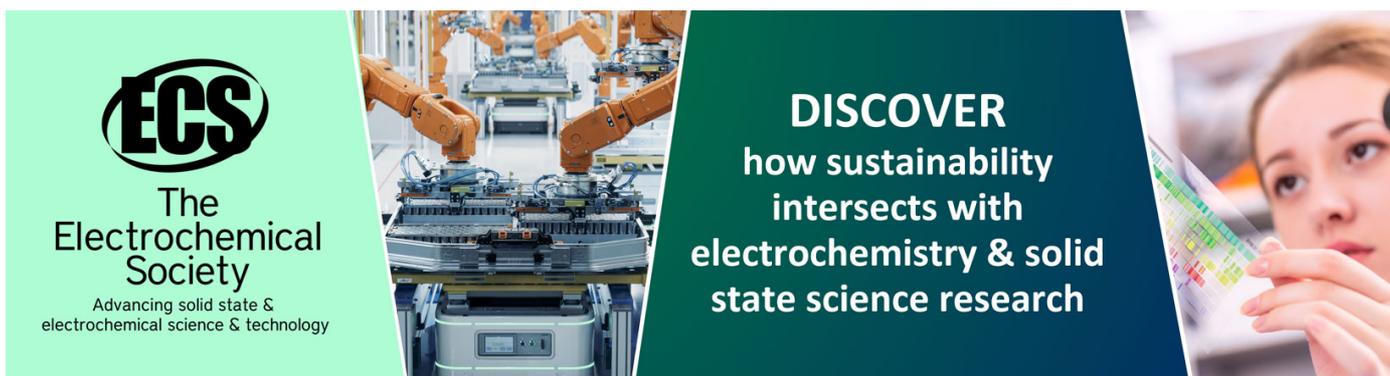
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# Vibration-intensity prediction of underwater blasting based on grey relational analysis and dimension theory

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**Abstract.** In addition to the distance from the blasting center and the charge amount, the influence of the water depth of the blasting zone and the difference in elevation between the measuring points are non-negligible for the vibration intensity of underwater blasting. Hence, the conventional Sadov's formula is no longer fully applicable for the vibration-intensity prediction of underwater blasting. Combined with the vibration data of underwater blasting projects, a grey relational analysis of the influencing factors for blasting-vibration intensity has been conducted. The obtained order of the influence degree, from high to low, is the charge amount, elevation of the measuring point, water depth of the blasting zone, and the distance from blasting center. A formula for vibration-intensity prediction that comprehensively considers the influencing factors was derived from dimension theory; this formula is similar to Sadov's formula. The comparison of the two prediction results showed that the average error of the formula considering the water depth of the blasting zone and the difference in elevation was below 10%. This showed a significant improvement in the prediction accuracy, compared with the Sadov's formula, indicating that this derived formula is applicable for the vibration-intensity prediction of underwater blasting on land measuring points.

## 1. Introduction

Blasting vibration is a damaging effect of underwater drilling blasting that cannot be neglected, and the monitoring, analysis, and prediction of its intensity have always been the main focus for safety assessment. There are numerous influencing factors for the damaging effect of blasting vibration, including terrain, formation properties, charging constitution, detonation mode, detonation order, and so on [1,2]. Due to the existence of water as the medium, the influencing factors of vibration intensity of underwater blasting increased significantly, among which the water depths of the blasting zone and the measuring points as well as the difference in elevation between the measuring points and the blasting zone became nonnegligible. The Sadov's formula has been widely used as a conventional prediction formula for blasting vibration velocity; however, it mainly considered two factors, the distance from blasting center and the charge amount, and integrates the effects of other factors into two undetermined coefficients. Therefore, when applied for vibration intensity prediction of



underwater blasting, the Sadov's formula will lead to relatively large error and cannot be fully used [3,4]. Nevertheless, because of the complexity of site conditions, the properties of rocks, and the heterogeneity of propagation medium, taking excessive factors into vibration prediction will lead to overfitting and affect the accuracy of prediction.

To improve the accuracy of vibration prediction of water drilling blasting, it is necessary to investigate the main factors affecting the blasting vibration intensity. Applying grey system, each factor's degree of effect can be quantitatively compared [5,6] and its contributing rate can be determined. Adopting the main factors as variables and the blasting vibration intensity as characteristic quantity, the formula of vibration prediction can be derived via dimensional analysis theory. Combined with the vibration test data of the land measuring points in underwater blasting projects and based on grey relational analysis and dimension theory, the research of vibration intensity prediction of underwater blasting was conducted. The prediction model of main influencing factors of blasting vibration was constructed, and the on-land propagation regularity of underwater drilling blasting seismic wave under test conditions was analyzed. By comparing the prediction accuracy of the Sadov's formula with this modified prediction formula, a more rational prediction model was ascertained that provided a reference for the research of the propagation regularity of underwater drilling blasting seismic wave and the vibration intensity prediction.

## 2. Grey relational analysis of vibration intensity

### 2.1. Grey relational theory

There are several relevant factors that affects blasting vibration velocity, and these factors also have certain correlations as well. Analyzing the degree of influence of different factors on blasting vibration is a difficult task. In the early 1980s, Julong Deng proposed a grey system theory that analyzed the degree of influence of different factors on one dependent variable [7,8] and soon gained popularity. This study provided a new method for exploring the connotative unknown fields in complex systems. The "information completely unknown" part of the research objects is called the "black system"; by observation and summarizing, the "black system" can be transformed into the "grey system" with small sample and poor information. Furthermore, after conducting the grey relational and grey clustering analysis to extract information, the transformation from "black system" to the "white system" with clear information was achieved.

In recent years, this theory has been integrated into various fields of natural science [9,10], and is also been widely used in blasting vibration analysis and prediction [11,12]. Grey relational analysis of grey theory can be applied to determine the degree of influence of multiple characteristic factors on the blasting vibration intensity, providing further reference for selecting dependent variables of blasting vibration prediction.

### 2.2. Grey relational theory

In addition to damaging underwater objects, vibration of underwater drilling has significant damaging effects on the buildings and structures of land pier. Vibration data obtained by monitoring land measuring points are listed in Appendix Table 1.

### 2.3. Grey relational analysis of vibration intensity

By performing grey relational analysis of data in Appendix table 1, the grey relational coefficients between different factors and blasting vibration intensity were obtained and listed in table 1.

**Table 1.** Grey relational analysis results for the influencing factors of vibration intensity on land measuring points.

	$v_z\text{-max}$	VCV	PPV	Sum
Distance from blasting center	0.775	0.752	0.730	2.257

Elevation of measuring points	0.794	0.776	0.754	2.324
Water depth of blasting zone	0.795	0.770	0.750	2.315
Total charge amount	0.812	0.795	0.769	2.376

The studied factors were sorted by degree of influence via grey relational analysis: charge amount > elevation of measuring points > water depth of blasting zone > distance from blasting center. Water depth, as an important factor of underwater drilling blasting vibration, cannot be neglected in the vibration intensity prediction of blasting. Different locations of measuring points result in different degree of influence of factors such as charge amount, distance from blasting center, water depth therefore, it is necessary to consider situations with different locations of measuring points for vibration prediction analysis of blasting. Hence, instead of applying the same prediction formula for vibration prediction, it is necessary to improve the formula by introducing factors such as water depths of the blasting zone and measuring points, elevations of on land measuring points, and so on.

### 3. Vibration intensity prediction formula based on dimension theory

#### 3.1. Dimensional analysis of vibration intensity of underwater drilling blasting

The vibration effect of underwater drilling blasting is affected by blasting source, site medium conditions (such as lithology, joints, geological structures.), water depth, distance from blasting center, and elevation difference [13–18]. According to the test records, there are 12 main physical quantities related to the propagation process of blasting seismic wave, as listed in table 2.

**Table 2.** Main physical quantities related to the vibration velocity of underwater drilling blasting.

No.	Symbol	Name	Dimension
Independent variables	$Q$	Charge amount	$M$
	$E_0$	Total energy of explosive	$ML^2T^{-2}$
	$R$	Horizontal distance from the explosive charge center to the measuring point	$L$
	$c$	Velocity of seismic wave	$LT^{-1}$
	$\rho$	Density of underwater rock medium	$ML^{-3}$
	$H$	Elevation of measuring points	$L$
	$d$	Water depth of measuring points	$L$
Dependent variables	$h$	Water depth of blasting zone	$L$
	$t$	Lasting time	$T$
	$F$	Particle vibration frequency	$T^{-1}$
	$v$	Particle vibration velocity	$LT^{-1}$
	$E$	Vibration energy	$ML^2T^{-2}$

In this table: Letters L, T, and M represent the dimensions of length, time, and mass, respectively.

According to Buckingham  $\pi$  theorem, from the perspective of dimensional analysis, the vibration velocity of the measuring point can be described as:

$$v = \Phi(Q, E_0, R, c, \rho, H, d, h, F, t, E) \quad (1)$$

According to table 3, the total number of quantities related to vibration velocity of underwater drilling blasting is 12. Q, R, and c are selected as independent variables, and  $\pi$  represents dimensionless quantity, then:

$$\pi = \frac{v}{Q^{\lambda_1} R^{\lambda_2} c^{\lambda_3}} \quad (2)$$

where  $\lambda_1$ ,  $\lambda_2$ , and  $\lambda_3$  are all undetermined coefficients.

According to the dimensional homogeneous theorem:

$$\dim v = LT^{-1} = (M)^{\lambda_1} (L)^{\lambda_2} (LT^{-1})^{\lambda_3} \quad (3)$$

Therefore, when  $\lambda_1 = 0$ ,  $\lambda_2 = 0$ , and  $\lambda_3 = 1$ :

$$\pi = \frac{v}{c} \quad (4)$$

Similarly, the other quantities can be described as:

$$\pi_1 = \frac{E_0}{Qc^2}, \quad \pi_2 = \frac{\rho}{QR^{-3}}, \quad \pi_3 = \frac{H}{R}, \quad \pi_4 = \frac{d}{R}, \quad \pi_5 = \frac{h}{R}, \quad \pi_6 = \frac{t}{Rc^{-1}}, \quad \pi_7 = \frac{F}{R^{-1}c}, \quad \pi_8 = \frac{E}{Qc^2} \quad (5)$$

Substituting equation (4, 5) into equation (1) gives:

$$\pi = \frac{v}{c} = \Phi\left(\frac{E_0}{Qc^2}, \frac{\rho}{QR^{-3}}, \frac{H}{R}, \frac{d}{R}, \frac{h}{R}, \frac{t}{Rc^{-1}}, \frac{F}{R^{-1}c}, \frac{E}{Qc^2}\right) \quad (6)$$

According to the grey relational analysis, the water depth is an important factor affecting the vibration intensity of underwater drilling blasting and must be considered in vibration prediction. The products and powers of different dimensionless quantities are dimensionless quantities [19,20]; hence, combining  $\pi_2$ ,  $\pi_3$ ,  $\pi_4$ , and  $\pi_5$  renders a new dimensionless quantity  $\pi_9$ :

$$\pi_9 = (\pi_2)^{1/3} \pi_3 \pi_4 \pi_5 = \left(\frac{\rho}{QR^{-3}}\right)^{1/3} \left(\frac{H}{R}\right) \left(\frac{d}{R}\right) \left(\frac{h}{R}\right) \quad (7)$$

Simultaneous (6) and (7) renders a specific functional relationship between  $v/c$  and  $\left(\frac{\rho}{QR^{-3}}\right)^{1/3} \left(\frac{H}{R}\right) \left(\frac{d}{R}\right) \left(\frac{h}{R}\right)$ , namely,

$$\frac{v}{c} \propto \left(\frac{\rho}{QR^{-3}}\right)^{1/3} \left(\frac{H}{R}\right) \left(\frac{d}{R}\right) \left(\frac{h}{R}\right) \quad (8)$$

Under same test site conditions, the rock density  $\rho$  and the velocity of seismic wave  $c$  can be considered as constants, therefore,

$$\ln v = \alpha_1 + \beta_1 \ln\left(\frac{\sqrt[3]{Q}}{R}\right) + \beta_2 \ln\left(\frac{H}{R}\right) + \beta_3 \ln\left(\frac{d}{R}\right) + \beta_4 \ln\left(\frac{h}{R}\right) \quad (9)$$

The Sadov's formula typically used for land blasting is

$$v_0 = k \left(\frac{\sqrt[3]{Q}}{R}\right)^\alpha \quad (10)$$

Taking the logarithm on both sides of equation (10) renders

$$\ln v_0 = \ln k + \alpha \left(\frac{1}{3} \ln Q - \ln R\right) \quad (11)$$

Let  $\ln v_0 = \ln v$ ,  $\ln k = \alpha_1$ , and  $\alpha = \beta_1$  then

$$\ln v = \alpha_1 + \beta_1 \left(\frac{1}{3} \ln Q - \ln R\right) \tag{12}$$

Substituting equation (12) into equation (9) gives:

$$\ln v = \ln v_0 + \beta_2 \ln\left(\frac{H}{R}\right) + \beta_3 \ln\left(\frac{d}{R}\right) + \beta_4 \ln\left(\frac{h}{R}\right) \tag{13}$$

Then

$$v = k \left(\frac{\sqrt[3]{Q}}{R}\right)^{\beta_1} \left(\frac{H}{R}\right)^{\beta_2} \left(\frac{d}{R}\right)^{\beta_3} \left(\frac{h}{R}\right)^{\beta_4} \tag{14}$$

where k is the influencing coefficient comprehensively considering distance and water depth;  $\beta_1$  is the attenuation coefficient indicating the influence of charge amount;  $\beta_2$  is the attenuation coefficient indicating the influence of elevations of the measuring points;  $\beta_3$  is the attenuation coefficient indicating water depth of measuring points;  $\beta_4$  is the attenuation coefficient indicating water depth of blasting zone; other variables have been defined before.

When the measuring points are on land, the factors affecting the vibration intensity includes water depth of blasting zone and elevation of measuring point. Therefore, the modified formula of vibration velocity is

$$v = k \left(\frac{\sqrt[3]{Q}}{R}\right)^{\beta_1} \left(\frac{H}{R}\right)^{\beta_2} \left(\frac{h}{R}\right)^{\beta_4} \tag{15}$$

#### 4. Prediction formula of vibration intensity

The vibration data of land measuring points in Appendix Table 1 were analyzed and data fitting was performed with the Sadov's formula (10) and formula (15) considering water depth of blasting zone and difference in elevation between measuring points. The fitting data are listed in table 3 and 4.

**Table 3.** Fitting data of formula (10) without considering difference in elevation.

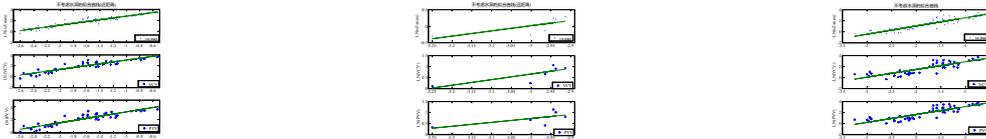
	$v_{z-max}$		VCV		PPV	
	<10	>10	<10	>10	<10	>10
K	76.432	47.026	102.822	21.048	136.061	74.344
A	1.626	1.220	1.639	0.796	1.692	1.120
CoD	0.960	0.918	0.954	0.863	0.966	0.895
F	833.444	122.622	729.398	69.045	1011.110	93.889

$$\begin{cases} v_{z-max} = 76.432 \left(\frac{\sqrt[3]{Q}}{R}\right)^{1.626} \\ VCV = 102.822 \left(\frac{\sqrt[3]{Q}}{R}\right)^{1.639} \\ PPV = 136.061 \left(\frac{\sqrt[3]{Q}}{R}\right)^{1.692} \end{cases} \quad (1.70 < R/\sqrt[3]{Q} < 10) \tag{16}$$

$$\begin{cases} v_{z-max} = 47.026 \left(\frac{\sqrt[3]{Q}}{R}\right)^{1.220} \\ VCV = 21.048 \left(\frac{\sqrt[3]{Q}}{R}\right)^{0.796} \\ PPV = 74.344 \left(\frac{\sqrt[3]{Q}}{R}\right)^{1.120} \end{cases} \quad (10 < R/\sqrt[3]{Q} < 20.12) \tag{17}$$

The fitting formulas represented by equation (16) and (17). Different from the vibration analysis results of underwater measuring points, the correlation coefficient of measuring points with short proportional distances, obtained by fitting with formula (10), was above 0.95, indicating relatively high fitting accuracy. However, the correlation coefficient of measuring points with longer proportional distances was noticeably smaller than that of the measuring points with shorter

proportional distances; it indicated large error using this formula for prediction, in other words, the prediction effect of measuring points with large proportional distances were not satisfying. The magnitude of F value also yielded the same results. The increase of proportional distance indicated the increase of distance from the blasting center and a far propagation path; moreover, the blasting zone was under water and the measuring points were on land, hence the attenuation of seismic wave during propagation would also vary depending on the terrain difference. It was observed from the test site that there were many obstacles and rock fractures between the land measuring points and the blasting zone, which resulted in the increase of transmission and refraction during the further propagation of seismic wave. This significantly affected the vibration intensity prediction.



Fitting curve of short distance      Fitting curve of long distance      Fitting curve graph  
**Figure 1.** Fitting curves of land measuring points without considering water depth.

**Table 4.** Fitting data of modified formula (15) considering difference in elevation.

	$v_{z-max}$		$VCV$		$PPV$	
	<10	>10	<10	>10	<10	>10
K	46.703	53.502	55.357	86.576	61.720	77.559
$\beta_1$	1.902	1.704	2.016	1.853	2.023	1.853
$\beta_2$	-0.466	0.045	-0.524	-0.285	-0.513	-0.224
$\beta_4$	-0.013	-0.414	-0.076	-0.524	-0.129	-0.512
CoD	0.871	0.738	0.851	0.786	0.841	0.796
F	90.063	43.158	76.089	56.320	70.639	59.709

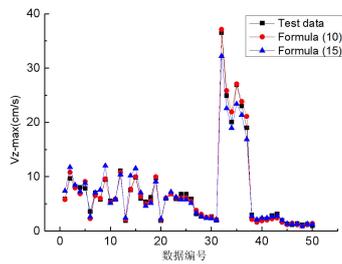
$$\begin{cases} v_{z-max} = 46.703 \left(\frac{\sqrt[3]{Q}}{R}\right)^{1.902} \left(\frac{H}{R}\right)^{-0.446} \left(\frac{h}{R}\right)^{-0.013} \\ VCV = 55.357 \left(\frac{\sqrt[3]{Q}}{R}\right)^{2.016} \left(\frac{H}{R}\right)^{-0.524} \left(\frac{h}{R}\right)^{-0.076} \\ PPV = 61.720 \left(\frac{\sqrt[3]{Q}}{R}\right)^{2.023} \left(\frac{H}{R}\right)^{-0.513} \left(\frac{h}{R}\right)^{-0.129} \end{cases} \quad (1.70 < R/\sqrt[3]{Q} < 10) \quad (18)$$

$$\begin{cases} v_{z-max} = 53.502 \left(\frac{\sqrt[3]{Q}}{R}\right)^{1.704} \left(\frac{H}{R}\right)^{0.045} \left(\frac{h}{R}\right)^{-0.414} \\ VCV = 86.576 \left(\frac{\sqrt[3]{Q}}{R}\right)^{1.853} \left(\frac{H}{R}\right)^{-0.285} \left(\frac{h}{R}\right)^{-0.524} \\ PPV = 77.559 \left(\frac{\sqrt[3]{Q}}{R}\right)^{1.853} \left(\frac{H}{R}\right)^{-0.224} \left(\frac{h}{R}\right)^{-0.512} \end{cases} \quad (10 < R/\sqrt[3]{Q} < 20.12) \quad (19)$$

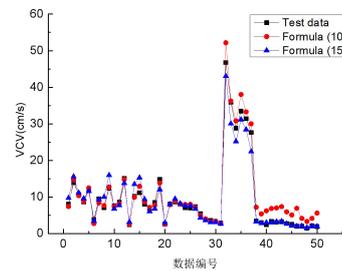
The fitting coefficients of vibration intensity prediction obtained by formula (15) considering water depth of blasting zone and difference in elevation of measuring points are listed in Table 4. The corresponding fitting formulas are 18 and 19. As listed in the fitting data table,  $\beta_2$  and  $\beta_4$  were had negative values, which indicated positive correlations of vibration intensity with water depth of blasting zone and elevation of measuring points. With the increase of water depth of blasting zone, the vibration intensity increased; with the increase of elevation of measuring points, the vibration intensity increased owing to the elevation effect. Regarding land blasting prediction, it is known that elevation is an essential influencing factor for vibration intensity. When the seismic wave of underwater drilling blasting propagates to the land, the terrain of the land is also affected by the propagation of seismic wave. The effect of terrain was taken into consideration as an influencing factor on prediction by statistically analyzing the elevation of measuring points, which could effectively improve the accuracy of the vibration intensity prediction. Two fitting formulas were used to fit the vibration data and their error values by comparing with the test values listed in table 5.

**Table 5.** Error values of different fitting methods.

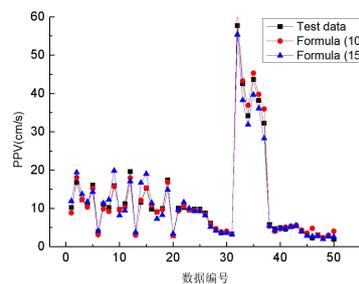
Number	$v_{z-max}$		VCV		PPV	
	formula (10)	formula (15)	formula (10)	formula (15)	formula (10)	formula (15)
1	0.376	0.023	0.039	0.035	0.135	0.014
2	0.692	0.121	0.576	0.133	0.854	0.150
3	0.554	0.310	0.976	0.103	1.302	0.127
4	0.275	0.042	0.386	0.060	0.307	0.114
5	0.283	0.034	0.491	0.223	0.412	0.249
6	0.373	0.158	0.358	0.012	0.313	0.097
7	0.118	0.317	0.055	0.549	0.203	0.087
8	0.382	0.023	0.454	0.014	0.365	0.043
9	0.341	0.072	0.191	0.226	0.100	0.144
10	0.119	0.062	0.176	0.081	0.118	0.035
11	0.008	0.029	0.092	0.062	0.079	0.100
12	0.008	0.128	0.054	0.024	0.020	0.119
13	0.089	0.083	0.030	0.043	0.042	0.208
14	0.002	0.184	0.046	0.110	0.009	0.225
15	0.222	0.003	0.362	0.035	0.340	0.165
16	0.163	0.012	0.351	0.110	0.303	0.198
17	0.071	0.182	0.277	0.087	0.182	0.133
18	0.220	0.053	0.210	0.176	0.153	0.053
19	0.289	0.157	0.273	0.050	0.174	0.097
20	0.208	0.093	0.192	0.005	0.134	0.107
21	0.047	0.142	0.108	0.088	0.031	0.052
22	0.132	0.092	0.229	0.323	0.227	0.106
23	0.186	0.116	0.097	0.128	0.213	0.046
24	0.043	0.052	0.059	0.051	0.049	0.018
25	0.480	0.112	0.046	0.105	0.228	0.117
26	0.644	0.108	0.508	0.150	0.578	0.013
27	0.245	0.049	0.053	0.048	0.080	0.100
28	0.276	0.089	0.090	0.057	0.236	0.112
29	0.333	0.045	0.152	0.021	0.291	0.088
30	0.006	0.008	0.264	0.196	0.195	0.054
31	0.024	0.097	0.152	0.140	0.237	0.025
32	0.007	0.457	0.215	0.460	0.204	0.213
33	0.017	0.001	0.011	0.002	0.022	0.033
34	0.037	0.043	0.094	0.093	0.076	0.044
35	0.008	0.016	0.119	0.092	0.160	0.191
36	0.029	0.008	0.036	0.051	0.021	0.096
37	0.062	0.008	0.034	0.038	0.149	0.047
38	0.006	0.009	0.047	0.032	0.106	0.357
39	0.005	0.010	0.019	0.016	0.075	0.254
error values	0.189	0.091	0.203	0.108	0.224	0.114



**Figure 2.** Comparison diagram of test data and prediction  $-v_{z-max}$ .



**Figure 3.** Comparison diagram of test data and prediction  $-VCV$ .



**Figure 4.** Comparison diagram of test data and prediction- $PPV$ .

Figure 2-4 were the comparison diagrams between the prediction data from two fitting formulas and the test data. The comparison indicated that blasting vibration intensity can be more accurately predicted when considering the water depth of blasting zone and the elevation of measuring points as the influencing factors on blasting vibration intensity, as the prediction data of these two factors were closer to the test data. table 5 lists the data from two fitting methods and the test data. Based on the average errors, the prediction accuracy of formula considering the water depth of blasting zone and the elevation of measuring points was enhanced, and the enhancement was specifically significant for the  $VCV$ . Therefore, it is necessary to consider these two factors in the modified formula. However, it can be seen from the figures that when the vibration intensity was large, the fitting values from Sadov's formula were closer to the test values, which indicated that when the vibration intensity was large the effect of difference in elevation between measuring points and blasting zone would decline, and the effect of distance from blasting center became most prominent. As the amount of such data was small, the formula for situations of large vibration intensity required further improvement to enhance the prediction accuracy. Comparing the prediction values of the Sadov's formula and the modified formula, the prediction accuracy was enhanced with the modified formula considering the effect of water depth, due to the nonnegligible influence of water depth on underwater rock vibration.

## 5. Conclusion

In this study, the influencing factors on vibration intensity of underwater drilling blasting were analyzed via grey relational analysis. The modified formula of the Sadov's formula considering the effect of water depth was derived based on dimensional analysis. On comparing the prediction accuracy of conventional Sadov's formula and the modified formula, the following conclusions can be drawn:

(1) As water environment is the unique operational circumstance for underwater drilling blasting, the effect of water depth on blasting vibration prediction cannot be neglected. Analyzing the vibration data via grey relational theory, the main factors affecting the underwater blasting vibration can be

obtained (in order from high to low: charge amount, elevation of measuring points, water depth of blasting zone, and distance from blasting center).

(2) By introducing the attenuation coefficient  $\beta_2$  that indicates the elevation of measuring points and the attenuation coefficient  $\beta_4$  that indicates the water depth of blasting zone, a modified formula has been proposed with elevation of measuring points and water depth of blasting zone.

(3) The application of modified formula that considered water depth has enhanced the prediction accuracy, nearly double to that of the conventional Sadov's formula.

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**Appendix Table 1.** Vibration data obtained by monitoring land measuring points.

Number	$R$ (m)	$H$ (m)	$h$ (m)	$Q$ (kg)	$v_{z-max}$ (cm/s)	$VCV$ (cm/s)	$PPV$ (cm/s)
1	58.851	14.38	8.73	2712	5.876	8.024	10.206
2	49.514	10.36	4.84	3832	9.689	13.88	16.787
3	40.915	7.05	6.79	1173	8.231	10.692	12.219
4	43.98	7.05	9.08	1104	8.014	8.615	10.808
5	49.415	7.05	5.08	2226	7.879	11.9	16.063
6	55.036	7.05	14.33	327	3.601	3.806	3.947
7	42.28	7.05	7.75	927	7.014	9.459	11.116
8	57.867	13.97	8.73	2712	5.793	7.092	10.248
9	48.23	13.97	4.81	3696	9.479	12.372	15.93
10	55.549	6.76	2.24	1173	5.557	7.6	9.734
11	50.169	6.76	2.76	1104	5.811	8.568	11.2
12	44.529	6.76	5.08	2226	11.12	15.075	19.598
13	57.78	6.76	14.33	327	1.942	2.402	3.336
14	47.054	14.38	5.78	2528	7.555	10.148	11.563
15	44.644	10.36	8.73	2712	9.893	11.135	15.299
16	67.59	12.22	4.84	3832	5.976	7.997	9.788
17	59.449	6.15	2.24	1173	5.354	6.799	9.023
18	54.26	6.15	2.76	1104	6.188	8.491	9.956
19	48.363	6.15	5.08	2226	9.735	14.777	17.399
20	60.982	6.15	14.33	327	1.926	2.576	2.868
21	46.417	6.15	7.75	927	5.964	8.003	10.033
22	44.744	7.05	7.36	1140	6.834	8.631	10.234
23	48.857	6.76	7.36	1140	5.932	7.972	9.598
24	51.055	6.14	7.36	1140	6.789	7.058	9.787
25	52.754	6.04	9.38	1247	6.818	6.968	9.798
26	56.601	6.17	9.38	1247	5.928	7.305	8.761
27	61.762	4.65	11.22	711	3.174	5.398	6.12
28	80.58	5.95	11.57	1104	2.668	3.845	4.29
29	87.611	7.05	11.57	1104	2.47	3.579	3.599
30	81.422	5.95	9.69	858	2.683	3.298	3.756
31	88.41	7.05	9.69	858	1.968	2.858	3.323
32	33.64	6.1	7.16	7728	36.525	46.749	57.716
33	41.863	6.77	7.16	7728	24.929	35.923	42.576
34	46.637	6.9	7.16	7728	20.065	28.818	34.147
35	38.151	6.1	6.74	6248	26.939	33.454	43.683
36	40.342	6.77	6.74	6248	23.026	31.422	38.18
37	46.646	5.57	6.74	6248	19.024	27.628	32.243
38	92.141	7.05	11.22	711	2.935	3.38	5.791
39	114.608	8.81	11.22	711	1.979	2.983	4.651
40	109.791	8.81	11.57	858	2.192	2.423	4.935

41	109.414	8.81	9.69	858	2.205	3.285	4.569
42	66.735	6.85	6.57	247	2.832	3.086	5.24
43	63.468	6.87	6.57	247	3.134	3.232	5.429
44	85.173	5.02	6.57	247	1.969	2.737	4.019
45	203.788	7.87	9.07	1353	1.33	2.534	2.945
46	227.635	7.87	4.96	1615	1.178	1.961	2.313
47	210.135	14.38	9.07	1353	1.368	1.98	3.121
48	217.115	14.38	4.96	597	1.139	1.416	2.372
49	222.382	14.38	10.09	1635	1.24	2.063	2.748
50	236.053	14.38	4.96	1615	0.971	1.877	1.942