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IN-GROUND VIBRATION PROPAGATION CHARACTERISTICS DURING UNDERGROUND BLASTING

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ABSTRACT

Purpose. In this study, we investigated the vibration propagation characteristics in ground caused by the explosion pressures during ground and underground blasting. In addition, the use of Styrofoam as a simulation medium, which represents the void during underground blasting, was investigated.

Methods. The investigation method is the measuring and comparing the vibrations using variable trinitrotoluene (TNT) charge amounts and underground volumetric spaces.

Findings. The regression analysis results based on experimental calculations indicated that the vibration levels were lower and vibration attenuation occurred more rapidly during underground blasting than those during ground blasting.

Originality. As the underground volumetric space increased, the vibration levels lowered and vibration attenuation became more gradual.

Practical implications. The use of Styrofoam to simulate the void in the underground space during blasting was deemed inappropriate, however, Styrofoam may be appropriate as a medium for low-impedance grounds.

Keywords: *explosion pressure, ground blasting, underground blasting, regression analysis, styrofoam*

1. INTRODUCTION

In selected military operations, explosives are used to destroy bridges or other above or below ground structures. To ensure complete destruction of the target, a large number of explosives are used. The ground vibrations caused by the explosive pressure of the detonation often causes secondary damage to the surrounding non-targeted structures.

In this study, we investigated the characteristics of in-ground vibration propagation caused by the explosion pressures during ground and underground blasting by measuring and comparing the vibrations using variable trinitrotoluene (TNT) charge amounts and underground volumetric spaces.

Specifically, the vibration levels and attenuation were measured and compared. In addition, the use of Styrofoam as a simulation medium, which represents the void during underground blasting, was investigated (Morin & Ficarazzo, 2006; Gheibie, Aghababaei, Hoseinie, & Pourrahimian, 2009; Kabwe, 2018).

2. METHODS

The vibration propagation characteristics were measured in a series of ground and underground blasting experiments using variable TNT charge amounts and underground volumetric spaces. Subsequently, regression analysis was performed to derive an equation for estimating the square-root scaled distance, which can accurately analysis the vibration propagation characteristics of a blast in an open environment (Akbari, Lashkaripour, Yarahamdi Bafghi, & Ghafoori, 2015; Kamel, Abdellah, Korichi, & Abderazzak, 2015; Singh et al., 2016).

2.1. Experiment setup

In this study, three experimental setups were used to reflect (1) ground blasting, (2) underground blasting, and (3) underground blasting using Styrofoam instead of an open void. Figure 1 shows the conceptual experimental setups for each of these blasting types.

The underground space was formed using an excavator. To prevent a direct delivery of the explosive detonation shock wave to the surface, an underground space must have adequate dimensions with the explosive placed at its center (Kumar, Choudhury, & Bhargava, 2016; Wojtecki, Mendecki, & Zuberek, 2017).

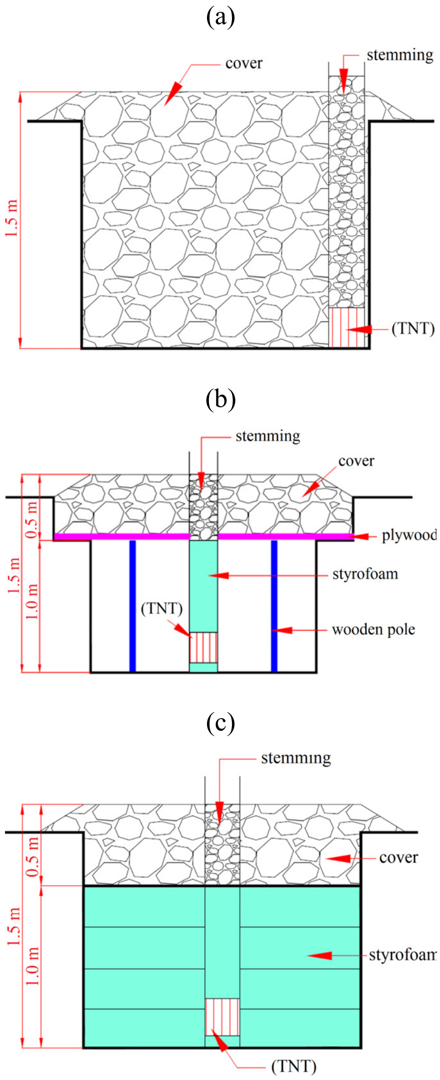


Figure 1. Conceptual experimental setups: (a) ground blasting; (b) underground blasting; (c) underground blasting using Styrofoam

However, due to the unstable ground conditions at the test site, a sufficient depth was not obtained. In addition, the plywood used as a top cover for the underground space did not withstand the weight of the earthen materials, resulting in insufficient coverage. Under these conditions, we estimated that a large proportion of the explosive force would have been concentrated at the top portion (cover) of the underground space, affecting the vibrations transmitted to the ground surface. To minimize these effects, we placed a layer of Styrofoam between the ground and the explosives, as shown in Figure 1.

We installed a vibrometer to measure the vibrations during each of the blasting experiments. Figure 2 shows the conceptual vibrometer installations. During a blasting experiment, the excavation dimensions of the underground space and subsequent recovering because of loose earthen materials can affect the vibration measurement accuracy (Nur Lyana, Hareyani, Kamar Shah, & Mohd Hazizan, 2016; Zhang, Yang, & Liu, 2016).

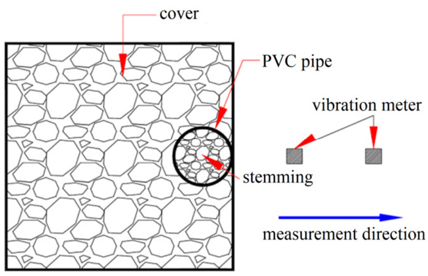


Figure 2. Vibrometer installation

To minimize the vibration propagation distortion stemming from the ground disturbance, we buried a loading pipe along the wall of the underground space and installed the vibrometer at some distance from the loose earthen materials.

2.2. Experiments

2.2.1. Ground blasting

To determine the baseline in-ground vibration propagation characteristics at the test site, we performed three separate ground blasting experiments using TNT charge amounts of 0.72, 1.44, and 2.88 kg. Figure 3 shows the different stages of a general ground blasting preparation process, which includes excavation and installation and burial of the loading pipe.

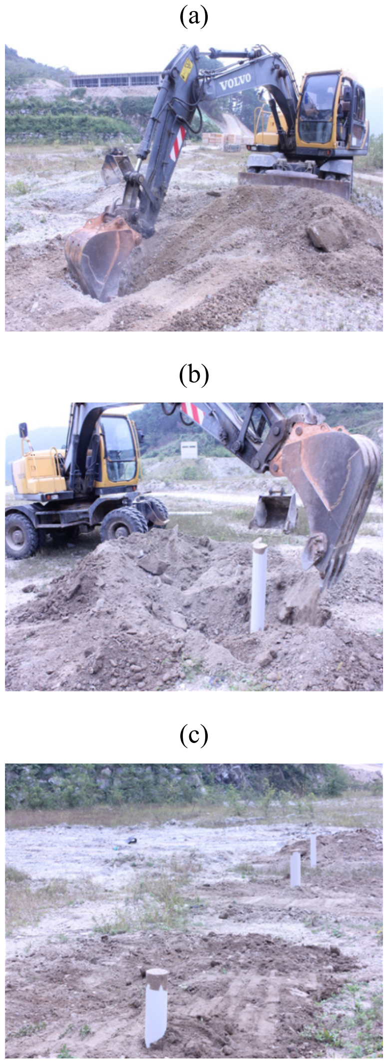


Figure 3. Preparation of the ground blasting experiment: (a) excavation; (b) pipe installation; (c) final setup

2.2.2. Underground blasting

To measure the in-ground vibration propagation characteristics during underground blasting, we performed five separate underground blasting experiments using TNT charge amounts of 0.72, 1.44, and 2.88 kg, and underground volumetric spaces of 1, 2, and 4 m^3. Figure 4 shows the different stages of a general underground blasting preparation process, which includes excavation, support pillar installation (required 4 m^3 space to support only the weight of the earthen material cover), and pipe/plywood installation and burial. As mentioned before, we placed a layer of Styrofoam between the ground and the explosives at the bottom of the pipe to minimize any explosive force concentration at the top portion of the underground space.

(a)

(b)

(c)

Figure 4. Preparation of the underground blasting experiment: (a) excavation; (b) support installation; (c) pipe installation

2.2.3. Underground blasting using Styrofoam

To investigate the use of Styrofoam as a simulation medium, which represents the void during underground blasting, we performed an experiment using a TNT charge amount of 2.88 kg and an underground volumetric space of 1 m^3. In this experiment, a 1 m^3 block of Styrofoam was used to fill the space. Figure 5 shows the different stages of a general underground blasting using Styrofoam preparation process, which includes excavation, TNT charge placement, and pipe fill-up and compaction.

(a)

(b)

(c)

Figure 5. Preparation of the underground blasting using Styrofoam: (a) excavation; (b) TNT placement; (c) pipe fill-up

To determine whether the buried Styrofoam acted as a void or a medium, we compared the results of this experiment with those of the ground and underground blasting experiments.

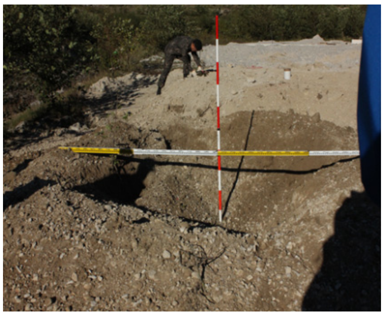
3. RESULTS AND DISCUSSION

3.1. Experimental results

Figure 6 show the ground, underground, and Styrofoam-based blasting results for a constant TNT charge amount of 2.88 kg. The pipe diameters differed in all three blasting experiments, and craters formed at the excavated depths prior to blasting. After the detonation of the explosives, we observed that ground blasting had the highest scatter distance, followed by underground blasting using Styrofoam and conventional underground blasting.

(a)

(b)



(c)

Figure 6. Blasting experiment results: (a) ground blasting; (b) underground blasting; (c) blasting using Styrofoam

This observation suggested that the Styrofoam layer acted as a low-impedance medium. During the underground blasting experiment using a constant TNT charge amount, an increased underground volumetric space resulted in a decreased crater width and a greatly decreased scatter distance. This observation indicated that the explosion pressure decreased as the underground volumetric space increased.

3.2. Regression analysis

The vibration data obtained from the ground, underground, and Styrofoam-based blasting experiments was used to support the subsequent regression analysis, which was performed to accurately model and predict the vibration propagation characteristics. Specifically, regression analysis was performed to derive equations for estimating the square-root scaled distance, which can accurately model the vibration propagation characteristics of a blast in an open environment. We performed regression analysis based on this study's experimental data to model the vibration propagation characteristics of a blast using the calculated square-root scaled distance (Avellan, Belopotocanova, & Puurunen, 2017). Table 1 lists the resultant square-root scaled distance equations and the associated correlation coefficients (*R*) for each of the experimental cases considered in this study. The general form of the square-root scaled distance equation is $V = K(SD^2)^{-n}$, where V is the peak particle velocity, SD is the scaled distance, and K and n are the site characteristic constants.

The square-root scaled distance equations estimated in this study for ground blasting were consistent with the vibration estimation equation of the Ministry of Land, Infrastructure, and Transportation (MOLIT) (Gui, Zhao, Zhou, Goh, & Jayasinghe, 2017). On comparing this study's estimated square root scaled distance equations for ground and underground blasting, we observed that the underground (conventional and Styrofoam-based) blasting cases had consistently lower K and higher n values than the ground blasting cases for a constant TNT charge amount of 2.88 kg.

Table 1. Estimated square root scaled distance equations for each experimental

Blast type	Volume, m^3	Case	Charge, kg	Square-root scaled distance equation	Correlation coefficient (*R*)
Ground	—	A	0.72	$V_{95\%} = 345.8(SD^2)^{-1.72}$	0.94
		B	1.44	$V_{95\%} = 62.7(SD^2)^{-1.66}$	0.95
		C	2.88	$V_{95\%} = 134.7(SD^2)^{-1.88}$	0.95
		D	All	$V_{95\%} = 123.7(SD^2)^{-1.50}$	0.84
Underground	1	E	1.44	$V_{95\%} = 168.8(SD^2)^{-1.96}$	0.93
		F	2.88	$V_{95\%} = 42.9(SD^2)^{-1.64}$	0.95
		G	All	$V_{95\%} = 75.4(SD^2)^{-1.78}$	0.94
	2	H	2.88	$V_{95\%} = 23.4(SD^2)^{-1.54}$	0.97
	4	I	2.88	$V_{95\%} = 3.8(SD^2)^{-0.99}$	0.95
Styrofoam-based underground	1	J	2.88	$V_{95\%} = 48.4(SD^2)^{-1.39}$	0.95

This observation suggested that at short distances, the vibration levels were lower and vibration attenuation occurred more rapidly (Tripathy, Shirke, & Kudale, 2016).

3.2.1. Vibration levels

Generally, vibration levels are indicated by their peak particle velocities. Figure 7 shows the comparison of the peak particle velocities estimated using regression analysis and measured during experimentation as a function of square root scaled distance for various ground (Case D) and underground (Cases G, H, I) blasting experimental cases.

The ground blasting case (Case D) had a flatter gradient and a higher K value (indicated as the intercept) than the underground blasting cases (Cases G, H, and I).

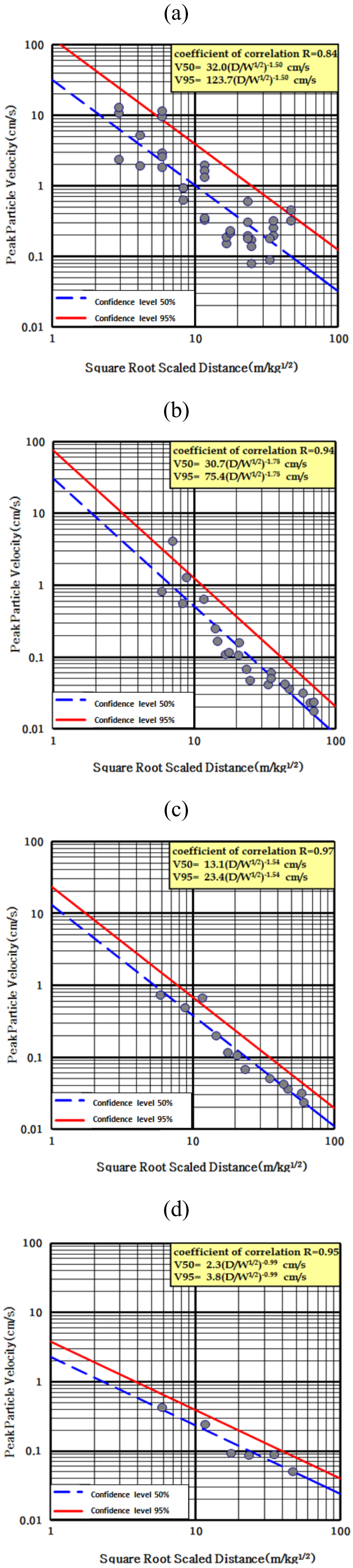


Figure 7. Comparison of peak particle velocities: (a) Case D; (b) Case G; (c) Case H; (d) Case I

This observation indicated that the vibration levels were higher, and vibration attenuation occurred more slowly during ground blasting. The comparisons among the underground blasting cases (Cases G, H, and I in Figure 7b – 7d) indicated that as the underground volumetric space increased (Cases G and H used a 2 m^3 space while Case I used a 4 m^3 space), the K and n values decreased, subsequently decreasing the vibration levels and moderating the vibration attenuation.

3.2.2. Vibration attenuation

To determine the vibration propagation characteristics during ground and underground (conventional and Styrofoam-based) blasting, a series of vibration attenuation comparisons were performed. First, this study's vibration attenuation results were compared with the vibration estimation equation obtained from the MOLIT. Figure 8 shows that the two sets of results are consistent.

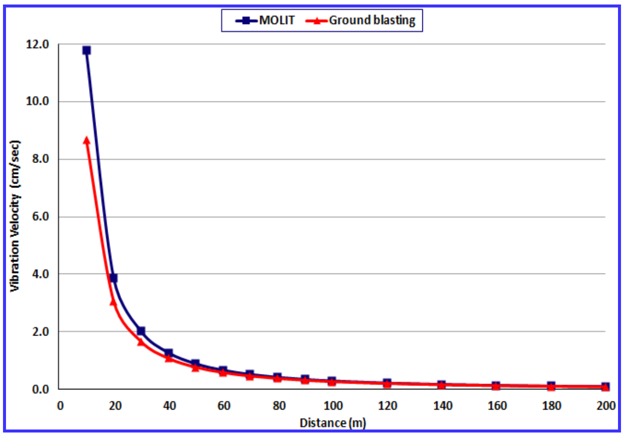


Figure 8. Comparison of the vibration results

Further, we compared the vibration attenuation for different TNT charge amounts (1.44 and 2.88 kg) and for different underground volumetric spaces (1, 2, and 4 m^3). Figure 9 and 10 show the results of these comparisons, respectively. The results indicated that the TNT charge amount did not significantly affect the vibration attenuation for the same underground volumetric space. Comparatively, the vibration levels clearly decreased as the underground volumetric space increased for the same TNT charge amount.

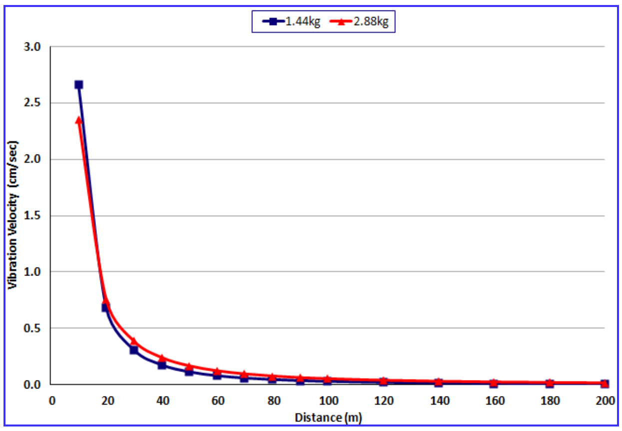


Figure 9. Vibration attenuation by TNT charge amount

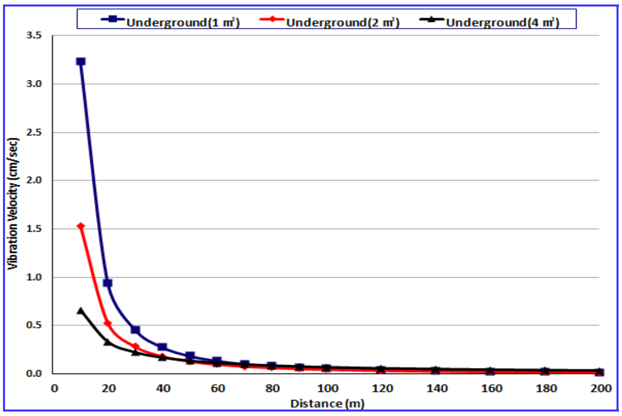


Figure 10. Vibration attenuation by the underground space

Figure 11 and 12 show the comparison between vibration attenuation during ground and underground blasting, during underground blasting and underground blasting using Styrofoam, and during ground and underground (conventional and Styrofoam-based) blasting, respectively. The results indicated higher vibration levels for ground blasting than underground blasting (Fig. 11). Underground blasting using Styrofoam had higher vibration levels than conventional underground blasting but had lower vibration levels than ground blasting (Fig. 12). The latter observation suggested that the use of Styrofoam to simulate the void in the underground space would not be appropriate. However, Styrofoam may be appropriate as a medium for low-impedance grounds.

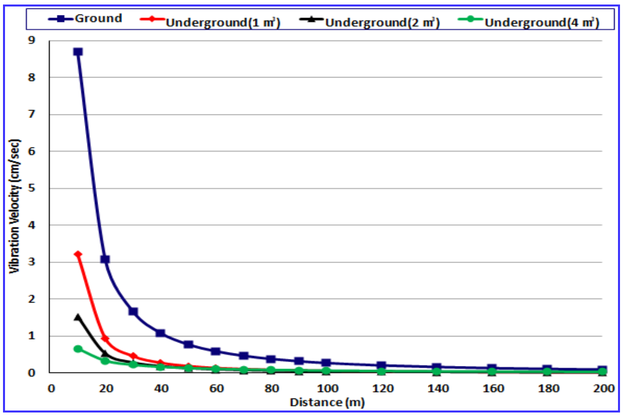


Figure 11. Comparison of vibration attenuation

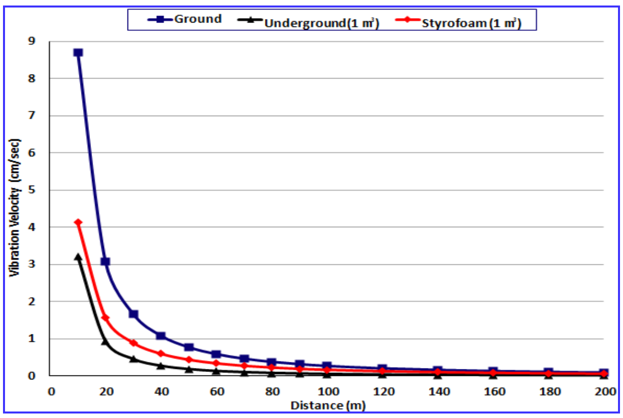


Figure 12. Comparison of vibration attenuation of Styrofoam

4. CONCLUSIONS

In this study, we investigated the characteristics of in-ground vibration propagation caused by the explosion pressures during ground and underground blasting by measuring and comparing the vibrations using variable TNT charge amounts and underground volumetric spaces. In addition, the use of Styrofoam as a simulation medium, which represents the void during underground blasting, was investigated. The key results of this study are summarized as follows:

– the vibration level and attenuation results estimated in this study for ground blasting were consistent with the results of the vibration estimation equation obtained from the MOLIT;

– the vibration levels were higher, and vibration attenuation occurred more slowly during ground blasting than during underground blasting. Conversely, the vibration levels were lower, and vibration attenuation occurred more rapidly during underground blasting than during ground blasting;

– the vibration attenuation during underground blasting was affected by the changes in the underground volumetric space but not by the changes in the TNT charge amounts;

– as the underground volumetric space increased, the vibration level decreased, and the vibration attenuation became more gradual;

– finally, the use of Styrofoam to simulate the void in the underground space was deemed inappropriate; however, Styrofoam may be appropriate as a medium for low-impedance grounds.

The results of this study substantially contribute to the state of knowledge regarding the vibration propagation characteristics during underground blasting. Future research on this topic will be considered.

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ПАРАМЕТРИ ПОШИРЕННЯ ВІБРАЦІЙ В ҐРУНТІ ПІД ЧАС ПІДЗЕМНОГО ВИБУХУ

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Мета. Вивчення параметрів поширення вібрацій у ґрунті, викликаних тиском під час наземних і підземних вибухів. Дослідження особливостей використання пінополістиролу в якості середовища моделювання, який виконує роль пустот під час вибуху.

Методика. Розроблено 3 експериментальних установки для відображення вибухових робіт на землі, підземних і підземних вибухів з використанням пінополістиролу замість відкритої порожнечі. Характеристики поширення вібрації було виміряно в серії наземних і підземних вибухових експериментів з використанням змінних величин заряду тротилу (0.72, 1.44 і 2.88 кг) і підземних об'ємних просторів (1, 2 і 4 м^3). Проведено регресійний аналіз для отримання рівняння характеристики поширення вібрації вибуху у відкритому середовищі. Для вимірювання вібрації під час кожного з вибухових експериментів встановлювався віброметр.

Результати. Регресійний аналіз на основі експериментальних даних дозволив зробити висновок про те, що рівень вібрацій був нижче і вібрації загасали швидше під час підземних вибухів у порівнянні з наземними. Визначено, що при підземних вибухових роботах з використанням пінополістиролу його шар діяв як середовище з низьким опором. Встановлено, що рівень вібрації і результати загасання, оцінені в цьому дослідженні для вибухових робіт на землі, відповідали результатами рівняння оцінки вібрації Міністерства землі, інфраструктури і транспорту (MOLIT). Встановлено, що на ослаблення вібрації під час підземних вибухів впливають зміни в підземному об'ємному просторі, але не зміни в обсягах заряду тротилу.

Наукова новизна. Науково встановлено і доведено, що зі збільшенням об'єму підземної порожнини знижується рівень вібрацій і тим рівномірніше відбувається їх згасання.

Практична значимість. Застосування пінополістиролу для моделювання підземної порожнини під час вибухових робіт не доцільно, однак, його можна використовувати в якості середовища для моделювання ґрунтів з низьким опором.

Ключові слова: *тиск вибуху, наземний вибух, підземний вибух, регресійний аналіз, пінополістирол*

ПАРАМЕТРЫ РАСПРОСТРАНЕНИЯ ВИБРАЦИЙ В ГРУНТЕ ВО ВРЕМЯ ПОДЗЕМНОГО ВЗРЫВА

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Цель. Изучение параметров распространения вибраций в грунте, вызванных давлением во время наземных и подземных взрывов. Исследование особенностей использования пенополистирола в качестве среды моделирования, которая выполняет роль пустот во время взрыва.

Методика. Разработаны 3 экспериментальных установки для отражения взрывных работ на земле, подземных и подземных взрывов с использованием пенополистирола вместо открытой пустоты. Характеристики распространения вибрации были измерены в серии наземных и подземных взрывных экспериментов с использованием переменных величин заряда тротила (0.72, 1.44 и 2.88 кг) и подземных объемных пространств (1, 2 и 4 м^3). Проведен регрессионный анализ для получения уравнения характеристики распространения вибрации взрыва в открытой среде. Для измерения вибрации во время каждого из взрывных экспериментов устанавливали виброметр.

Результаты. Регрессионный анализ на основе экспериментальных данных позволил сделать вывод о том, что уровень вибраций был ниже и вибрации затухали быстрее во время подземных взрывов по сравнению с наземными. Определено, что при подземных взрывных работах с использованием пенополистирола его слой действовал как среда с низким импедансом. Установлено, что уровень вибрации и результаты затухания, оцененные в этом исследовании для взрывных работ на земле, соответствовали результатам уравнения оценки вибрации Министерства земли, инфраструктуры и транспорта (MOLIT). Установлено, что на ослабление вибрации во время подземных взрывов влияют изменения в подземном объемном пространстве, но не изменения в объемах заряда тротила.

Научная новизна. Научно установлено и доказано, что с увеличением объема подземной полости снижается уровень вибраций и тем равномернее происходит их затухание.

Практическая значимость. Применение пенополистирола для моделирования подземной полости во время взрывных работ не целесообразно, однако, его можно использовать в качестве среды для моделирования грунтов с низким импедансом.

Ключевые слова: *давление взрыва, наземный взрыв, подземный взрыв, регрессионный анализ, пенополистирол*

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