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Technical Note

Experimental study on amplitude change of blast vibrations through steps and ditches

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1. Introduction

Drill and blast is the most common method in rock excavation engineering. Usually, these blast operations are performed at the site close to inhabited places or factory premises. And ground vibrations induced by blasting may have an adverse effect on the nearby buildings. For this reason, it is essential to make an accurate prediction of the vibrations, and therefore, define a safe charge of explosives during the blast operations [1,2].

In general, ground vibrations are closely related to: (1) the explosive charge, Q, and (2) the distance between the explosion source and the target point, D. Most of the predictor equations are developed based on it. The following are some prevalent ones [3].

USBM (Duvall and Fogelson) [4]:

$$PPV = K(Q^{1/2}/D)^{\alpha} \tag{1}$$

Ambraseys–Hendron [5]:

$$PPV = K(Q^{1/3}/D)^{\alpha} \tag{2}$$

Langefors–Kihlstrom [6]:

$$PPV = K(Q^{2/3}/D)^{\alpha} \tag{3}$$

Indian Standard Predictor [7]:

$$PPV = K(Q^{3/2}/D)^{\alpha} \tag{4}$$

where PPV stands for the peak particle velocity at the target point, and K and α are site constants, which can be determined by regression analysis according to site investigation results. A general form can be given by

$$PPV = KQ^{\beta}/D^{\alpha} \tag{5}$$

where β is another constant. It means that the ground vibrations attenuate exponentially with distance but increase with the quantity of explosives. As a whole, the equation reveals the correlation among the vibrations, explosive quantity and the distance.

However, it is also reported that, at a site with complex and varied terrains and landforms, these ordinary equations may under- or over-estimate the blast vibrations. For example, Khandelwal and Singh [3] and Nateghi [2] investigated blast vibrations in hilly terrains and found that the vibrations obtained by ordinary prediction equations are significantly deviated from those by field tests. Similar observations were reported by Spyros and Fotis [8] and Cao and Lee [9].

For this case, in the last few decades, many studies have been conducted to investigate the effects of varied terrains, such as highwalls or ditches, on blast wave propagation, through field investigations, theoretical analysis and numerical simulations. It has been observed conceptually that a highwall, i.e. terrain elevation, helps to

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magnify blast vibrations, whereas a damping ditch acts as vibration absorber.

For example, Masahiko and Masayoshi [10] studied the magnifying effect of an upward step when Rayleigh waves pass through it. They found that the vibration amplitude increases with the ratio of step height, H, to vibration wavelength, λ. In the case of a slope, the gradient has a bearing on this magnifying effect. Research by Ashford et al. [11] pointed out that when the slope gradient reaches to 1:2, the vibration magnifying begins to occur, and it becomes more striking when the gradient is greater than 1.7:1. Pedersen et al. [12] investigated the magnifying effects for vertical and horizontal component of blast vibrations, and suggested that the magnifying coefficient of horizontal component is greater than that of vertical one. Similarly works have been conducted by Geli et al. [13].

As to the studies on the attenuation effect of ditch, Zhang et al. [14] and Masahiko and Yoshiro [15] found that the blast vibrations will reduce by as much as 70% when they pass through a damping ditch based on site investigations and numerical simulations. The attenuation effect is dependent on the ratio of ditch depth, H, to vibration wavelength, λ. The greater the H/λ is, the faster the vibration attenuates, whereas the ditch width has no obvious effect on vibrations.

The above researches are generally performed at level ground site. Trial works have also been conducted to study the effects of varied terrains on blast vibrations. For example, Javier et al. [16] developed a FEM model to predict the complex ground vibrations. Adjustment factors of geological structures, the relative position of blast holes and the measuring point, faults and terrain elevations etc. have been introduced in it. The re-calibrated model reproduced velocity histories with good results. An artificial neural network (ANN) method has also been increasingly used in the *PPV* prediction in recent years [17,18]. It reveals a high correlation between the prediction equations obtained by this method and the test results at the site with complex and varied terrains.

In the present paper, the magnifying effects of an upward step and the attenuation effects of a damping ditch on blast vibrations are discussed respectively based on blast tests at a moderately weathered granite site, located at the construction site of a nuclear power plant in China. The influencing factors, including the height of the step, the depth and width of the ditch, the position of the step or the ditch, have been analyzed in detail. Then, empirical expressions considering topographic effects have been brought forward to forecast blast vibrations at the site with different topographic features.

Fig. 1. Vibration sensor and data logging instrument of the vibration monitoring system.

2. Basic descriptions of field tests

The test site is a foundation pit of a nuclear power plant under construction, mainly composed of moderately weathered granite, with density of 2610 kg/m^3, elastic modulus of 49 GPa, Poisson's ratio of 0.19 and compressive strength of 150 MPa. Blast tests have been performed and monitored at the level ground, step and ditch site, respectively. All the blast holes are approximately 3 m deep, with cylindrical charge of emulsion explosives in the range of 1–3 kg.

Blast tests and vibration measurements were carried out during the foundation excavation. In this process, different topographic features yielded. For example, the step height, ditch depth and width kept increasing, and the distance between explosion source and the step or ditch kept changing. The parameters of these site conditions and the related measured results have been compared and analyzed, as is discussed in the following.

A digital data logging system, consisting of a vibration sensor and a data collecting instrument, was employed to record the velocity histories of the monitoring target (see Fig. 1). The sensor was fixed to rock surface by early strength gypsum and can acquire vibration signals in three perpendicular directions, with principal frequency (PF) in the range of 0.5–1 kHz, vibrations of 10^{-5} to 0.35 m/s and sampling rate of 1 to 50 kHz. At the step site, (see Fig. 2a), the vibration sensor was installed at the top of the upward step. On this occasion, the topographic features that magnify the blast vibrations

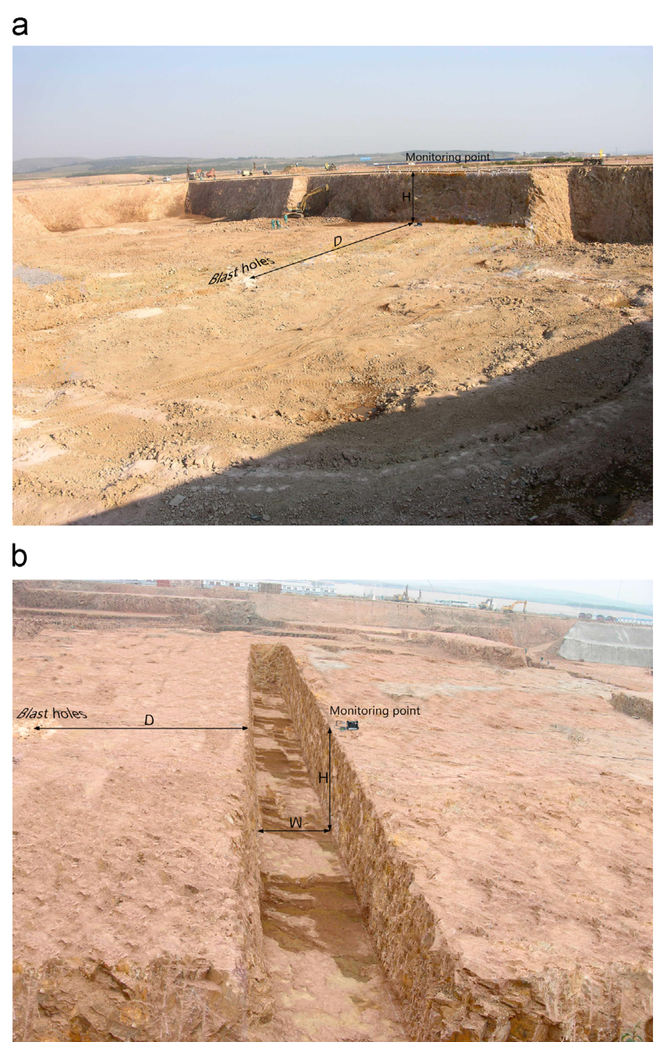

Fig. 2. Blast vibration measurements in sites with different topographic features. (a) Upward slope site. (b) Damping ditch site.