EXPERIMENTAL STUDY ON DETERMINING THE EFFECTIVE RADIUS OF BLASTING AND PILE-DRIVING ACTIVITIES ON CONSTRUCTION STRUCTURES

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Abstract - Accurately determining the effective impact radius of construction-induced vibrations, such as those caused by vibratory roadbed compaction, pile driving, and rock blasting, is essential for ensuring the safety of adjacent structures and minimizing disputes in infrastructure projects. This study experimentally investigates the propagation and attenuation of shock waves generated by blasting and pile-driving activities in typical geological conditions in Central Vietnam. Field measurements of peak particle velocity, acceleration, and noise levels were conducted using calibrated sensors in accordance with national standards (TCVN 7378 and QCVN 27:2010/BTN-MT). The experimental data were analyzed to derive empirical relationships between vibration intensity and distance from the source, enabling the estimation of safe construction distances for various structural types. The results show strong agreement between theoretical models and in-situ measurements, validating the proposed approach and offering practical guidance for infrastructure design, construction planning, and regulatory compliance.

Key words - Effective radius; ground vibration; shock wave; peak particle velocity (PPV); blasting; pile driving; construction impact

1. Introduction

In recent years, numerous construction projects, particularly those related to transportation infrastructure, have experienced significant delays due to unresolved disputes between construction contractors and neighboring property owners. These disputes often stem from the appearance of structural cracks in adjacent buildings, attributed to ground vibrations generated by nearby construction activities. However, the lack of a robust scientific basis to clearly determine the responsible party has complicated resolution efforts (see Figures 1 and 2). This situation underscores the urgent need for systematic research into the influence range of ground vibrations caused by various construction activities, including vibratory compaction, pile driving, and quarry blasting.

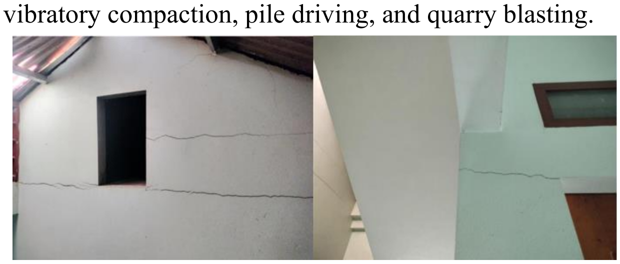

Figure 1. Cracks in residential houses caused by ground vibrations from blasting during road construction in Yen Bai Province

Figure 2. Cracks in residential buildings due to vibrations from pile driving for the embankment construction in Quang Nam Province

Several studies by Vietnamese researchers have addressed vibration impacts on structures. Notably, Nguyen Lan and colleagues [4, 5] investigated ground vibrations induced by blasting and pile-driving equipment commonly used in road and bridge construction. Their findings emphasized that the extent of vibration impact depends not only on the construction method and equipment type, but also on the distance between the source and the structure, as well as on local soil conditions and geotechnical properties. In a related study, Hoang Phuong Hoa et al. [3] conducted both experimental and numerical simulations to analyze vibrations generated by vibratory rollers and proposed practical solutions to mitigate their effects on adjacent structures.

International research efforts have also contributed valuable theoretical and experimental insights. Pioneering work by R. D. Woods and colleagues [6, 7] established fundamental wave propagation models for vibratory sources in soil media. Further investigations by Rainer et al. [8] and Balan et al. [11] focused on ground vibrations caused by pile-driving activities in various strata. Shahab Hosseini et al. [10] assessed the effects of blasting-induced vibrations in mining operations, while Hoang Nguyen et al. [9] applied Artificial Neural Networks (ANNs) to predict ground vibration intensity from blasting. In addition, Zhang et al. [13] examined the mechanisms through which vibratory rollers contribute to the formation of structural cracks during roadbed compaction.

While these studies have contributed to the understanding of vibration-induced damage, most primarily concentrate on identifying causes rather than proposing effective countermeasures or quantifying safe distances. This paper aims to address that gap by experimentally evaluating the impact radius of blasting and pile-driving activities on nearby structures. Field results are then compared with theoretical models to validate the findings and support the development of practical guidelines for infrastructure project design and management.

2. Theoretical basis of wave propagation

2.1. Wave propagation equation

Based on the theory of an ideal, infinite, homogeneous, and isotropic elastic medium, the velocities of P-waves (longitudinal waves) and S-waves (shear waves) are determined by the following formulas:

Wave equation: $Z = A\sin\left(\omega t+\varphi\right)$ (1)

Wave velocity equation: $\dot{Z} = A\omega\cos\left(\omega t+\varphi\right)$ (2)

Wave acceleration equation:

$$\ddot{Z} = -A\omega^2\sin\left(\omega t+\varphi\right) \quad (3)$$

Where: A is the amplitude of oscillation (m); ω is the angular frequency (rad/s), $\omega = 2\pi/t$; t is the period of oscillation (s), $t = 2\pi/\omega$; f is the frequency of oscillation (s^{-1}, Hz), $f = 1/t$, $f = \omega/2\pi$; c is the wave propagation speed (m/s), $c = f\lambda$; v is the peak velocity (m/s), $v = 2\pi f A$; λ is the wavelength (m), $\lambda = c/f$; φ is the phase angle (rad).

The wave propagation equation in soil [6, 7] for P-waves (longitudinal waves) is as follows:

$$V_P = \sqrt{\frac{E\left(1-\nu\right)}{\rho\left(1+\nu\right)\left(1-2\right)}} \quad (4)$$

For S-waves:

$$V_S = \sqrt{\frac{G}{2\rho\left(1+\nu\right)}} \quad (5)$$

For Rayleigh waves (R-waves), R-waves are generally slower than shear waves:

$$V_R \approx 0{,}92.V_S \quad (6)$$

where E is the Young's modulus (MPa); G is the shear modulus (MPa); ρ is the material density (kg/m^3); ν is the Poisson's ratio.

In construction projects such as bridge and road development, building construction, and hydropower or irrigation works, a variety of heavy equipment is employed, such as vibratory rollers for soil compaction, pile drivers, and explosives for rock excavation. These activities generate ground vibrations originating from specific sources, referred to as vibration sources. The intensity of vibration typically attenuates with increasing distance from the source. A location is considered effectively unaffected when the vibration amplitude is negligible and both velocity and acceleration remain below thresholds that could cause structural damage. Accordingly, a construction site is deemed safe when the induced vibrations fall within permissible limits that do not compromise the structural integrity of nearby buildings or infrastructure.

2.2. Wave attenuation in the ground

Geometric wave attenuation: The geometric attenuation of waves due to the source of vibration can be determined by the following expression:

$$A_2^{HH} = A_1^{HH}\left(\frac{r_1^{HH}}{r_2^{HH}}\right)^n \quad (7)$$

where A_2^{HH} is the amplitude of oscillation at a distance r_2^{HH}(m); A_1^{HH} is the amplitude of oscillation at a distance r_1^{HH}(m); n is a coefficient dependent on the type of wave: n=1/2 for Rayleigh waves, n=1 for body waves (P and S waves) and n=2 for surface waves.

Material-Dependent wave attenuation: The attenuation of waves due to the material (the ground) is determined by the following formula:

$$A_2^{VL} = A_1^{VL}e^{-\alpha\left(r_2^{VL}-r_1^{VL}\right)} \quad (8)$$

where A_2^{VL} is the amplitude of oscillation at a distance r_2^{VL}(m); A_1^{VL} is the amplitude of oscillation at a distance r_1^{VL}(m); α is the absorption coefficient, which is defined as, α=2πDf/c where: α is the absorption coefficient (m^{-1}); D is the material attenuation coefficient (Hzs); f is the frequency of oscillation (Hz); c is the wave propagation speed (m/s).

3. Experimental analysis

Field experiments were carried out at multiple construction sites in the Da Nang city area to evaluate the impact of ground vibrations generated by two primary sources: rock blasting for excavation and pile driving during transportation infrastructure development. The experiments involved deploying specialized vibration monitoring equipment to measure key parameters such as peak particle velocity (PPV), acceleration, and noise levels induced by these construction activities.

It should be noted that soil properties, including elastic modulus (E), shear modulus (G), and Poisson's ratio, were not explicitly modeled or measured during the experiments. Instead, their influence is implicitly incorporated into the empirical relationships derived from the measured data. These relationships, particularly those correlating the radius of influence with peak vibration velocity, were established through interpolation of the experimental results.

3.1. Equipment used for the experiments

To develop a system capable of capturing short-term ground vibrations from construction activities and supporting long-term monitoring of continuous vibration sources, all system components were selected and configured to comply with national standards TCVN 7378:2004 and QCVN 27:2010/BTN-MT [1, 2]. The hardware setup utilizes commercially available components, as detailed below:

Signal Acquisition and Conversion Unit: The system employs the cDAQ-9191 signal acquisition unit in conjunction with the NI 9205 module, which supports up to 32 analog input channels. Both components are manufactured by National Instruments (USA), as illustrated in Figure 3.

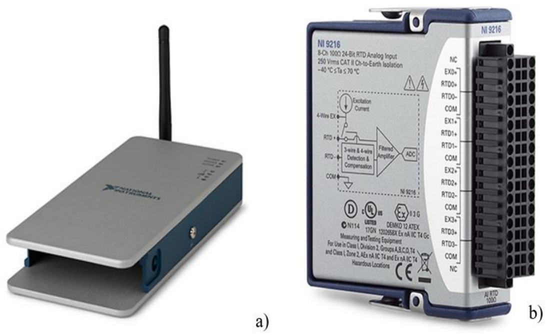

Figure 3. *Signal Acquisition and Conversion Unit: a) NI cDAQ 9191 Card, b) NI 9205 Card*

Sensors: Ground motion is measured using two types of sensors: a Geophone velocity sensor with a sensitivity of 28.05 mm/s per volt, and an Accelerometer 4030 with a sensitivity of 1000 mV/g. These are shown in Figure 4.

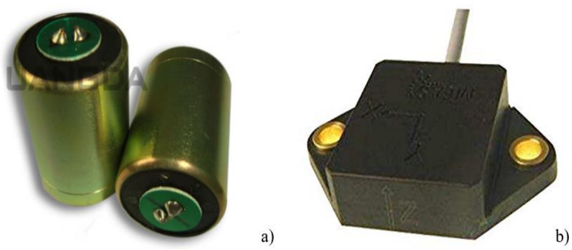

Figure 4. *Sensors Used in the Experiment:*
a) Geophone Velocity Sensor, sensity 28.05 m/s/volts
b) Accelerometer 4030 Sensor,sensity 1000 mV/g

All sensors has parameters comply with TCVN 7378:2004 and has calibration sheets.

All sensors conform to the specifications outlined in TCVN 7378:2004 and are accompanied by calibration certificates to ensure measurement accuracy.

The entire measurement system is interfaced with a computer, where data acquisition and processing are conducted using custom-developed software based on the LabVIEW platform (Figure 5).

Figure 5. *Connect measuring device to computer*

3.2. Experimental results of vibration impact measurement from blasting

The objective of this experiment is to quantify the impact of ground vibrations generated by blasting activities during rock excavation, which is commonly carried out to support infrastructure development in Da Nang City and surrounding provinces. The study specifically focuses on evaluating the effect of these vibrations on nearby residential structures located around an active quarry site. The layout of the vibration measurement points used in the experiment is presented in Figure 6.

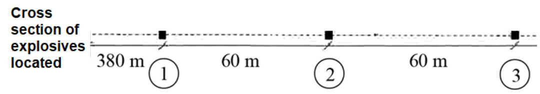

Figure 6. *Layout diagram of blasting measurement points*

The experimental formulas are used to determine the velocity, acceleration, and noise levels of the vibration during the experiment, based on the following formulas:

$$PPV = 3E + 19 * R^{-7.231}$$
$$A = 2E + 18 * R^{-7.623} \quad (9)$$
$$S = 1309.7R^{-0.489}$$

where PPV is peak particle (mm/s), A is acceleration (g), S is noise (dBA), R is the radius of the placement of the equipment relative to the vibration source (m).

The processed experimental data were used to establish empirical curves illustrating the relationship between vibration intensity, specifically velocity, acceleration, and noise level, and distance from the blast source. These relationships are presented in Figures 7 to 9.

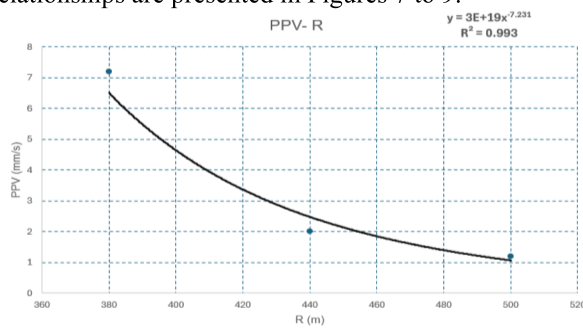

Figure 7. *Relationship between vibration velocity V (mm/s) and radius R (m) for 1.5 T of explosives*

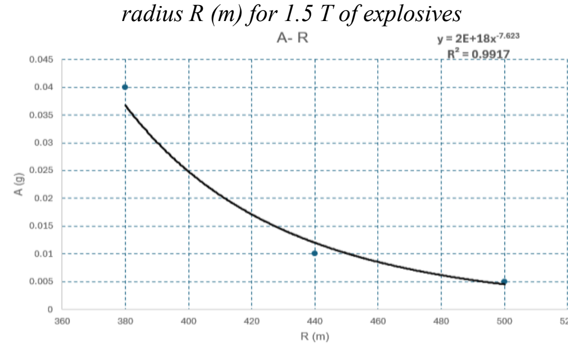

Figure 8. *Relationship between vibration acceleration A (g) and radius R (m) for 1.5 T of explosives.*

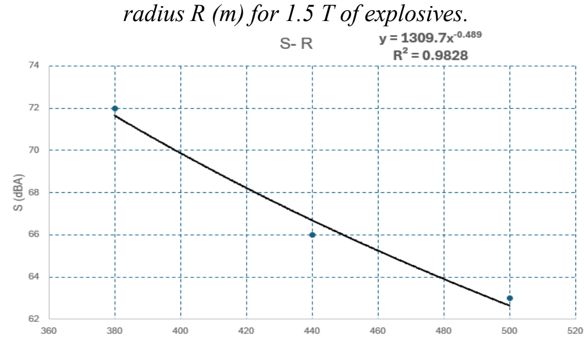

Figure 9. *Relationship between noise level S (dBA) and radius R (m) for 1.5 T of explosives*

Based on the experimentally derived relationships and in accordance with the standards TCVN 7378 and QCVN 27:2010/BTN-MT, the permissible vibration thresholds were used to determine the corresponding limiting (safe) radii from the blasting source, as follows:

For a permissible peak particle velocity (PPV) of 4.7 mm/s, the estimated impact radius is R = 407 m;

For a permissible vibration acceleration of 0.55G, the impact radius is R = 370 m;

For a permissible noise level of 70 dB(A), the impact radius is R = 400 m.

As an illustrative case, the vibration velocity spectrum recorded at a monitoring point located 380 meters from the blast source is presented in Figure 10.

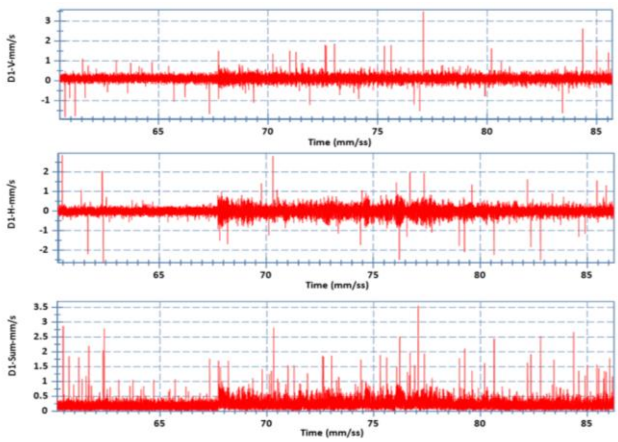

Figure 10. *Vibration velocity spectrum V-t due to 1.5 tons of explosives at point number 1 (Figure 6)*

3.3. Experimental results of vibration impact measurement from pile

This experiment aims to determine the effective impact radius of ground vibrations generated during the driving of reinforced concrete piles (35 × 35 cm cross-section, 18 m length) for a transportation embankment project. The source of vibration is a COBELCO K35 pile-driving hammer.

Following data acquisition and processing, empirical curves were developed to represent the relationship of PPV-R from the vibration source under different loading conditions. These relationships are illustrated in Figures 11 and 12.

From the experimental curve, the impact radius for each loading condition can be determined, as shown in Tables 1 and 2.

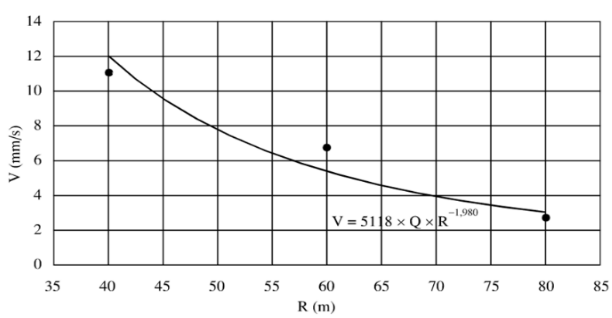

Figure 11. *PPV-R Relationship for measurements along the roadway*

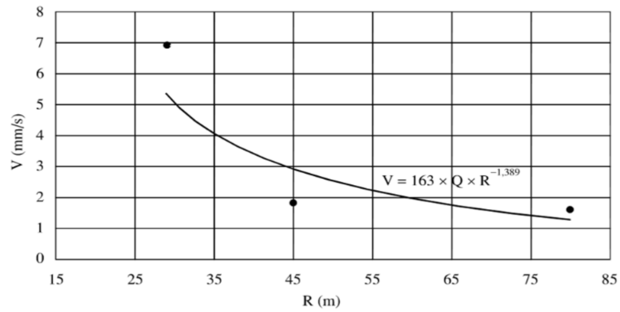

Figure 12. *PPV-R relationship for measurements perpendicular to the roadway*

Table 1. *Impact radius from pile driving along the roadway - loading condition parallel to the road centerline*

Maximum hammer force of COBELCO K35 (tons)	**Impact radius R (m) based on limit velocity**		
	Type I Structure (V_{gh} = 20.43mm/s)	Type II Structure (V_{gh} = 5.20mm/s)	Type III Structure (V_{gh} = 3.11mm/s)
3.5	30.60m	61.10m	79.20m

Table 2. *Impact Radius from Pile Driving Along the NTT Road - Loading Condition Perpendicular to the Road Centerline, Residential Side*

Maximum hammer force of COBELCO K35 (tons)	**Impact radius R (m) based on limit velocity**		
	Type I Structure (V_{gh} = 20.87mm/s)	Type II Structure (V_{gh} = 5.43mm/s)	Type III Structure (V_{gh} = 3.22mm/s)
3.5	10.80m	28.50m	41.60m

A comparison of the measured vibration velocities under the two loading conditions reveals that, at equal distances from the vibration source, the condition involving loading perpendicular to the road centerline, on the residential side, produces lower vibration velocities. This reduction is attributed to the damping effects of the asphalt concrete pavement and the presence of drainage ditches on both sides of the roadway, which attenuate wave propagation.

4. Conclusions

This study has experimentally assessed the effective impact radius of ground vibrations generated by typical construction activities, including rock blasting and pile driving, with a focus on applications in transportation infrastructure. The key conclusions are as follows:

The experiments successfully quantified the vibration impact range, expressed in terms of PPV, acceleration, and noise level, for both blasting and pile-driving operations under real construction conditions in the Da Nang region. These empirical relationships provide a reliable basis for estimating safe distances to adjacent structures.

The results demonstrate that the effective impact radius varies depending on both the vibration source and site-specific conditions, such as soil composition and the presence of surface features (e.g., pavement and drainage systems). For example, wave attenuation was observed to be greater when pile driving occurred perpendicular to the road centerline due to the damping effects of asphalt and roadside infrastructure.

The experimentally derived impact thresholds align well with Vietnamese national standards (TCVN 7378 and QCVN 27:2010/BTN-MT), confirming their applicability in practical scenarios. These findings can support regulatory agencies and project stakeholders in establishing scientifically grounded buffer zones during the planning and approval stages of infrastructure projects.

The insights obtained from pile-driving experiments are particularly valuable for construction activities near sensitive structures such as heritage buildings, religious sites, or densely populated residential are as where vibration mitigation strategies must be carefully designed.

Overall, the study contributes empirical evidence and practical guidance for evaluating and managing vibration impacts in civil construction, thereby reducing the risk of damage claims, enhancing safety, and supporting sustainable infrastructure development.

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