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Research Paper

The effects of ground vibration induced by construction activities of urban railways in Hanoi

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Many construction activities such as pile driving, drilling, roadbed compaction, drilling and blasting tunnels can cause ground vibration, which affects buildings and people nearby. If the wave intensity is high while the distance to neighboring buildings is close, the presence of damage in buildings is inevitable. Determination of the vibration radius which can cause damage in surrounding structures regarding each source of vibration is a necessary requirement for planning, construction technology selection and design method. It can minimize risks to surrounding buildings. The content of this article presents the measurement method to accurately estimate the vibration level of the construction activities of Hanoi pilot urban railway line 3 passing the busy Kim Ma street, Hanoi. High sensitivity vibration accelerometers are gathered in lines from the vibration source. It is shown that predicting the radius of the impact of construction site vibrations to neighboring buildings is possible. If the level of vibration is high then measures can be taken to prevent damage caused by the construction of the Hanoi pilot urban railway line. From obtained results, some solutions are proposed to minimize and avoid possible negative impacts.

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1 Introduction

The world's major cities are now experiencing a dramatic increase in their population. That has led to a rapidly growing demand for public transport and civil engineering systems. The lack of infrastructure is largely due to the highcost of land clearance in the urban area. Mega cities in the world are expanding underground transport infrastructure systems [1, 2]. In Vietnam, Hanoi and Ho Chi Minh city are implementing three pilotmetro lines. During constructing this system, vibration will cause discomfort to people who live near the route. For instance, it may damage structures if the resonance occurs. This is a huge concern for the authorities, that is to ensure the safety of the existing constructions.

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In order to measure and evaluate vibrations at construction sites, many standards in the world that have set limits, guidance on assessing damage that can occur from construction activities. Some of them can be listed, such as DIN 4150-3: 1999 Structural Vibration - part 3: The effect of vibration on structures [3], British Standard 7385-2: 1993 Evaluation and measurement of vibration in buildings, Part 2,guidance on the extent of damage due to vibrations from the ground [4]. In Vietnam, the methods of measuring and evaluating the effects of ground vibrations are mostly based on the limit thresholds specified in TCVN 7378: 2004 [5]. However, the measurement and determination of ground vibrations using the standard only serve as proof to evaluate the safety of the observed structure. The standard can not identify a safe zone for other structures surrounding the affected area of construction sites along the urban routes. High-cost implementation with many measurement points, complex instrumentation, and machines are the requirement in this standard.

At the pilot urban railway line in Hanoi city, the construction of the underground slope is in progress with specialized excavators, newly applied in Vietnam. Operation of large-capacity excavators leads to strong vibration of the surrounding ground, which potentially destructs neigh boring structures.

The measurement and research of ground vibration at this location contribute to the prediction of the propagation of vibration waves from the vibration source to the surrounding environment. Results of the study can be used to propose appropriate construction measures to ensure construction safety and minimize potentially dangerous incidents.

The article proposes a solution to measure and evaluate the safe area under the effects of vibration sources from the construction site. Accordingly, vibration measurement is optimized by reducing the number of measurement points. From the measurement results, it is possible to preliminarily assess the safety zone for structures adjacent to the construction site.

2 Theory of ground vibration

Ground vibration is essential process of soil particles being transferred by stimulating force move from one particle to another [6]. Continuous motion from one particle to the next one leads to large-scale propagation, that affects surrounding objects. When the vibration intensity is strong enough, the ground may not ensure the bearing capacity for the structures placed on it. This vibration will affect the construction. The resonant frequency of the structure can destroy the structure [3-5, 7].

Construction activities will create vibration and spread in the environment in the form of waves e.g. body waves (waves propagate inside the ground), and surface waves, which are transmitted along a surface (usually a surface above the ground) [8, 9] . The most popular types of waves are:

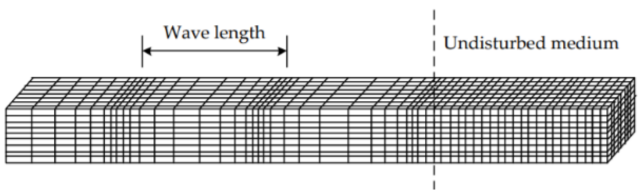

Fig. 1 – Characteristics of P waves

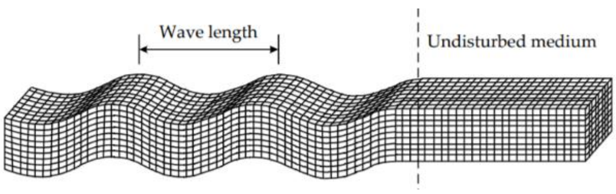

Fig. 2 – Characteristics of S waves

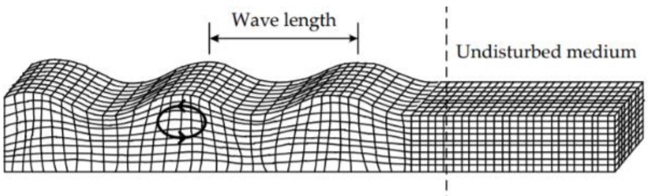

Fig. 3 – Characteristics of R waves

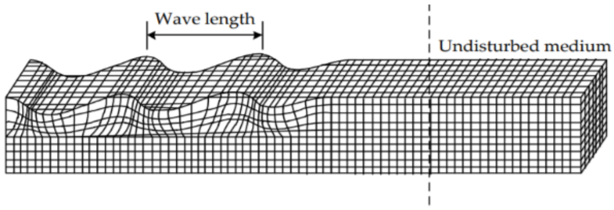

Fig. 4 – Characteristics of L waves

Many experimental formulas were proposed to determine the speed limit for each type of vibration source to evaluate the impact on the surrounding structures. Some typical experimental formulas are listed as follows:

Table 1 – Experimental formula for calculating the maximum particle velocity

No	Formulas	Note
1	$ppv = k\left(\frac{\sqrt{w}}{r}\right)^x$	ppv : maximum specific velocity (*mm/s*); r : distance from the source (*m*); w : the source energy causes vibrations. k and r - Experimental parameters determined from the graph of relationship V and R on a logarithmic axis This equation is only used when there are several test measurements on the scene [10].
2	$ppv = k_s\sqrt{n}\left[\frac{A}{R+\mathrm{w}}\right]^{1.5}$	Proposed for vibrating roller [6] k_s depend on probability of vibration n : the number of devices; A : the rated amplitude of the device; w : the width of the device (*m*).
3	$ppv = k_t\sqrt{n_d}\left[\frac{A^{1.5}}{(x+L_d)^{1.3}}\right]$	k_t : depend on probability of vibration n_d : the number of devices; L_d is the device – width [11, 12] x : distance from the source
4	$ppv \le k_p\left[\frac{\sqrt{W}}{r^{1.3}}\right]$	Applies to piling For piles with rejection: $k_p = 5$ For piles with no rejection: $1 \le k_p \le 3$, depending on soil type; W is the energy per device cycle; r is the distance from the source to the test site [13].
5	$ppv \le \frac{180}{x^{1.3}}$	x : the distance from the source to the test site Apply for tunneling [6]

In this paper, the authors focus mainly on the form of vibration source using great weight to exert force on the ground and propose to apply Dowding 2000's experimental formula [9], which does not require information of surrounding geology and the coefficients of complexity, however, gives relatively accurate results.

$$ppv = 67\left(\frac{r}{\sqrt{mh}}\right)^{-1.1} \quad (1)$$

ppv = maximum specific velocity (mm/s); r: distance from the source (m); m: drop weight (ton); h = drop height (m)

3 Case Study

3.1 Location and measuring equipment

The urban railways in Hanoi city have been started to construct underground sections. The authors conducted a measurement campaign at the site. Many heavy machines which generate the high intensity of vibration, were used at the construction site. These machines can cause a significant influence on ground vibration and surrounding buildings.

Table 2 – Geotechnical design parameters for geological units at Ha Noi metro pilot 3

Soil Properties	GU1_s	GU3&4	GU5a	GU5b	GU7&8
Type of soil	Sands	Clay	Clay	Sands	gravel
Unit weight (kN/m^3)	19	18	20	20	21
Dry unit weight (kN/m^3)	16	11	16	10	11

Fig. 5 – Construction site of ramp and surrounding buildings

Fig. 6 – Source of vibration – Walls construction machine D-walls

The geology at the construction site is shown in the following figure:

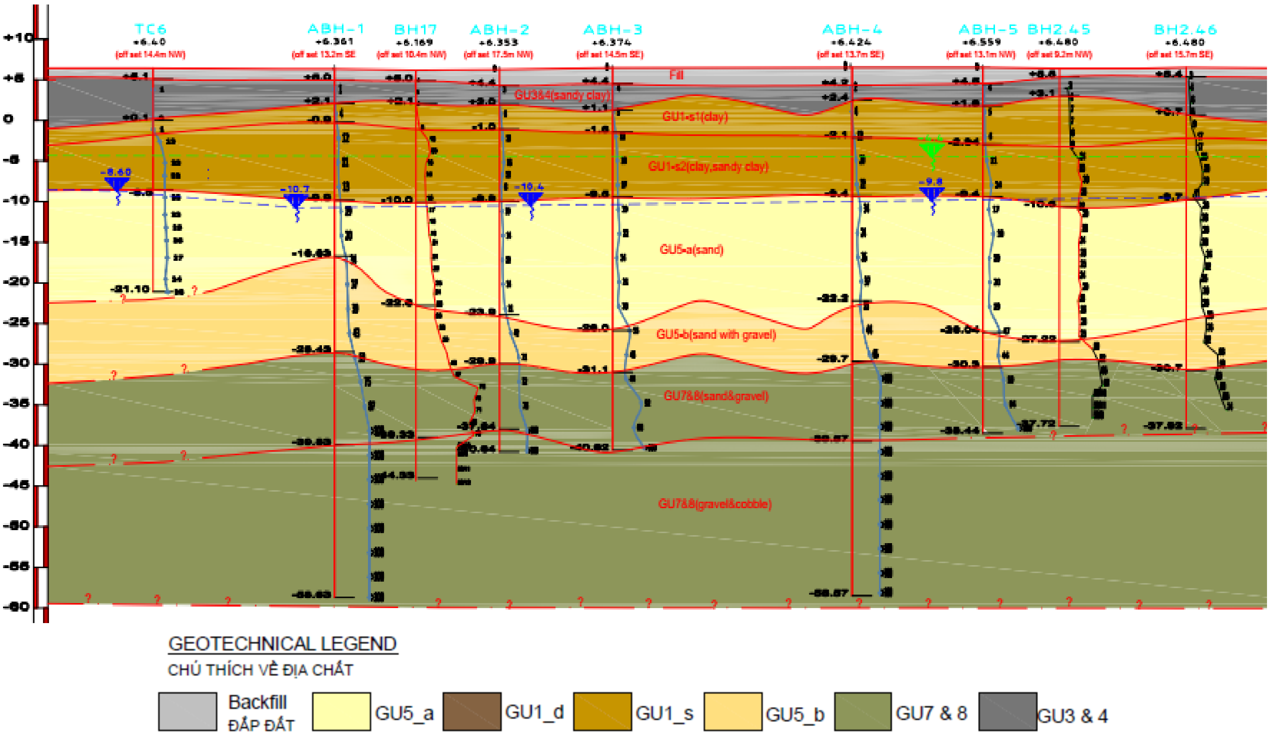

Fig. 7 – geology at the construction site Ha Noi metro pilot 3

Part of the underground construction is done by specialized excavators, with the specifications as shown below:

Table 3 – Excavator specifications

Specifications	Weight	High	Wattage	Drop height
Peach bucket	30 T	3 *m*	-	25 *m*
Rotating crane	20 T	30 *m*	-	-

Stemming from the above theories, measurement and evaluation methods are built as follows:

- Measurement of the soil surface adjacent to the construction site.
- Evaluate the safety of neighboring buildings based on the ground velocity or maximum particle velocity at the soil surface.

The vibration measuring equipment system usually includes: vibration sensors(accelerometers), data acquisition systems (DAS), software collecting, and data processing. Selecting the sensor type is very important in order to properly assess the oscillation. Usually, vibration sensors are divided into two groups: velocity sensor (geophone) widely used in measuring structural vibration and accelerometer. The requirements for equipment according to TCVN 7378:2004 [5] are as follows: Frequency range 1 Hz-100 Hz, non-linearity 10%; velocity range 0.01 *mm/s* – 500 *mm/s*.

To measure the magnitude of the impact due to vibration from the construction activities of the railways, acceleration sensors placed on steel anchors are used to record dynamic response of the ground during construction process.

Devices for the measurement campaign are shown as follows:

Fig. 8– Acceleration sensor

Fig. 9– Data acquisition system

Fig. 10– Computer with specific software

Fig. 11– Steel anchor

3.2 Experimental measurement of ground vibration

Accelerations are located on the anchors which are submerged in the soil at least 50 *cm* and are placed near the considered buildings. This allows to gain vibration signal of the ground around the center of vibration.

On a straight line, 3 measurement points are arranged at 3.5 *m*, 8.5 *m*, 12.5 *m* from the center of vibration. Four lines in different directions were measured for comparison purpose. For each measurement, the recorded results should include specific time: before excavating, during excavating and after excavating. Therefore, we can identify the differences in one implementation cycle to be able to evaluate the overall effect of the construction on ground vibration and surrounding buildings.

Fig. 12– Measurement points and data acquisition

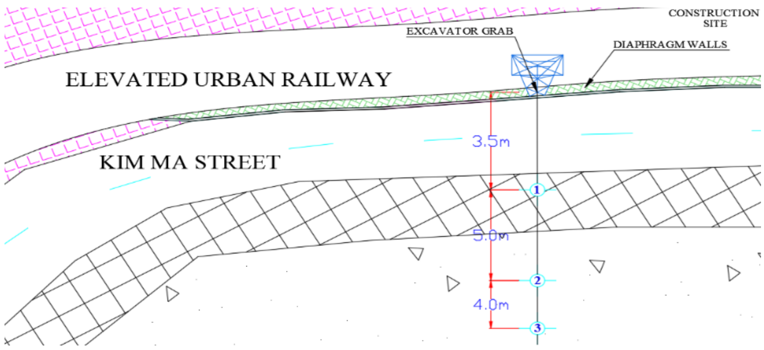

Fig. 13– The location of actual vibration measurement

3.3 Results of measurement and assessment of ground vibration

The processing data is conducted using MATLAB. the signals obtained from field measurements are processed for comparison and evaluation [14, 15].

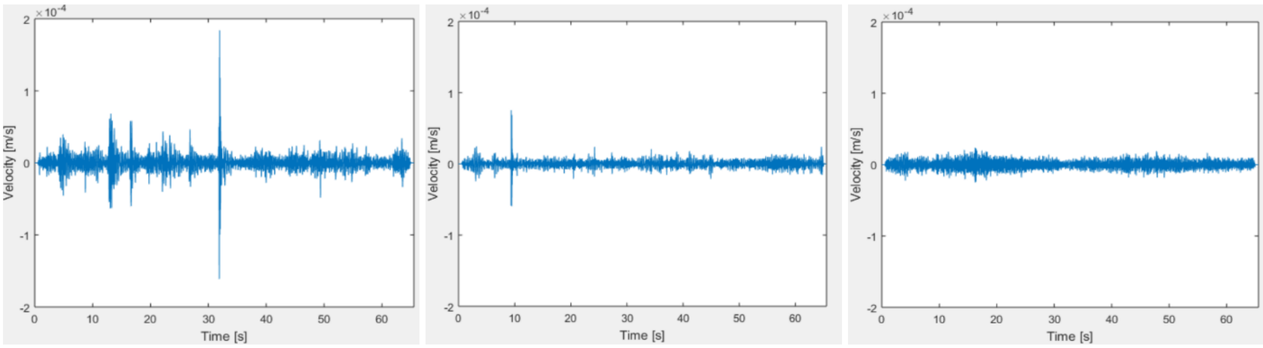

Fig. 14– Velocity chart on time domain from the three measurement

Information of vibration source regarding construction machines: the height of dropping bucket 25 *m* (from the point of dropping bucket to the point on the ground), the mass of bucket is 30 ton. The maximum velocity at locations from the center of vibration 3.5 *m*, 8.5 *m*, 12.5 *m*, is shown in the following table:

Table4 – Theoretical and experimental calculation results

Number	Distance from the center of vibration (*m*)	PVV theoretical calculations (*m/s*)	PVV field measurement (*m/s*)	Deviation
1	3. 5	6.44	6.5	0,93%
2	8.5	2.42	2.26	6,6%
3	12.5	1.587	1.697	6.5%

In the absence of an empirical exact assessment, the Dowding 2000's formula can be used to calculate the maximum ground velocity for a preliminary assessment of the safety of the building against vibration:

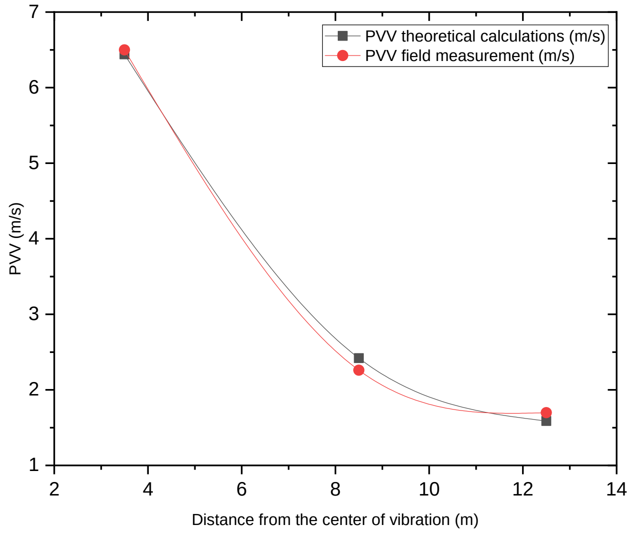

Fig. 15 – Relationship between maximum ground velocity and distance to vibration source

It can be seen that the largest velocity reduction on the ground between experimental and theoretical formula has similarities. Corresponding to the distance is large enough, the maximum speed on the ground ensures safety for the project. Based on this decline chart, it is possible to predict the radius of the impact of construction site vibrations to neighboring buildings, thereby taking measures to prevent damage caused by the construction of the Hanoi pilot urban railway line.

The decrease in velocity amplitude can be assessed through calculating and measuring at least 3 wave amplitude values at 3 points with an increasing distance. A nonlinear curve passing through those 3 largest values, is considered to be the decrease in the amplitude of the oscillation in wave propagation. Accordingly, the safety of the neighboring buildings more than 12.5 meters away from the vibration source can be ensured. The results have a good agreement with the recommendations according to current standards and the project's monitoring results [3-5, 7].

4 Conclusion

Many construction activities related to road infrastructure create ground vibration which can affect people as well as cause damage in buildings or affect residents in surrounding buildings, and consequently, create complaints between the people and the construction party. Therefore, the assessment of the possibility of damage in buildings and construction works by various sources, especially due to urban railways traffic, is a matter of concern.

The prediction method of ground vibration, unlike physical measurements, cannot describe vibration according to their individual frequency components (frequency spectrum). Therefore, their output is limited to the amplitude of vibration, usually to the maximum particle velocity.

The experimental method of assessing the impact of urban railways construction on ground vibration and surrounding buildings can be used to make assessments on safety issues for surrounding buildings in metro construction activities in Hanoi City.

In the absence of actual measurement, empirical formulas that have been studied and published for each subject included in the evaluation can be used. The Dowding 2000 formula has a simple calculation. It was used to calculate maximum ground velocity for a preliminary assessment of a building's safety against vibration from construction activities.

The results of the research can be used as a useful reference for consulting units, students, lecturers, and graduate students who interested in the field of construction health monitoring.

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