EXPERIMENTAL STUDY OF GROUND VIBRATION CAUSED BY CONSTRUCTION ACTIVITIES OF METRO LINE 1 PROJECT IN HO CHI MINH CITY

NGUYEN THI CAM NHUNG[1], DANG TRONG HUY[2],
NGUYEN HUU QUYET[1], TRAN NGOC HOA[1]
[1]University of Transport and Communications, No 3 Cau Giay Street, Hanoi, Viet Nam
[2]Transport Engineering Design Joint Stock Incorporrated South
Corresponding author's email:ncnhung@utc.edu.vn

Abstract: *Construction activities such as piling, drilling, compacting, etc ... can cause ground vibrations that possibly affecting neighboring buildings and the surrounding environment severely. Especially, construction activities in urban areas with high population density, adverse impacts on surrounding buildings are inevitable. Determining the vibration radius of each vibration source that can cause damage to the surrounding structures plays an important role in minimizing the negative impacts of construction activities on neighboring buildings and the surrounding environment. The content of this article presents measurement methods to determine ground vibration behaviour. The results show that the method possibly estimates the vibration level of the construction of Metro line 1: Ben Thanh – Suoi Tien, Ho Chi Minh city accurately. From the obtained results, some solutions are proposed.*

Keywords: *Ground vibration, construction activities, Metro Line.*

Received: 10/03/2021 Accepted: 13/03/2021 Published online: 31/05/2021

I. INTRODUCTION

For large cities with a high population density and an increasing transportation demand, it is extremely important to provide the optimal form of transport. With its prominent features that are suitable for the conditions of major cities, the Metro system has developed rapidly and been deployed in most major cities in the world. Metro is an urban railway system consisting of Mass Rapid Transit, Light Rail Transit, and Monorail. This is an optimal overall design consisting of trains, rails, stations, and integrated surrounding areas. This requires a large amount of investment [1].

In Vietnam, the rapid development of the two largest cities, Hanoi and Ho Chi Minh City, has put increasing pressure on the technical infrastructure system, including the urban transport system. Traffic congestion is increasingly common, affecting the air environment, landscape, human health as well as economy, etc. To deal with this problem, numerous solutions have been proposed in which urban railway lines are considered as one of the most workable solutions. The metro system tends to play an important role in lowering costs and reducing travel time since this form of transport uses separate lanes and does not cause any conflicts with others. For example, motorcycles and cars expend around 35-45 minutes, 60-70 minutes, respectively, on traveling 10 km in the inner city, whereas Metro only spends approximately 15-20 minutes for the same distance. Therefore, this form of transport is evaluated as a promising solution to solve existing traffic problems in the inner city such as traffic congestion, traffic accidents as well as reducing travel time.

Although the metro system [2-4] possibly brings great benefits to the transport system, the process of implementing the metro system also exerts negative effects. It is clear that the metro project is located in the city center, passing through many important structures of high historical value. Moreover, the process of construction operation and exploitation also use heavy machinery affecting surrounding structures and environments.

Figure 1. *Metro Line 1: Ben Thanh-Suoi Tien (red line – 19.7km, 14 stations) [5]*

Figure 2. *Construction of Ben Thanh Station*

One of these effects is the vibration caused by construction machines. From dimensional features to the types of machinery used in construction, all of which seem to cause vibrations affecting the environment as well as people [6-8]. In addition, with increasing concerns about the impact of the process of constructing metro systems, the need to improve the ability to predict ground vibrations is essential. However, the current standards, as well as guidance on this issue, do not have specific studies that can apply for the urban railway line 1 construction project: Ben Thanh – Suoi Tien, Ho Chi Minh city.

Therefore, this paper aims to analyze the effect of vibration sources caused by the construction activities of metro projects on the surrounding structures. Based on that result, the most suitable construction methods can be adopted. This plays a vital role in reducing the negative impacts of construction activities on neighboring buildings and the surrounding environment.

II. MAIN CONTENTS

Vibration analysis is the process of monitoring, evaluating the condition and making predictions about possible vibrations [9-11]. For the vibration caused by the construction process, the vibration analysis can give the characteristics of the vibration, evaluate the performance of construction machinery on the site, thereby analyzing the possibilities and risks. mechanism and extent of impacts of such impacts on the surrounding area. The process of analyzing vibrations during construction is usually done in the Project's Environmental Impact Assessment Program.

There are many types of ground vibrations, which include the following types: Continuous vibration affects the ground for a long time and continuously. This kind of vibration may occur due to the activities of road construction (rolling the roadbed) or the construction of digging underground structures. The deactivated vibration (pulse) is the rapid growth up to the extreme threshold of the vibration and then fades out. The damping vibrations are commonly seen in the form of a sudden force effect on the ground during piling or dam construction, with a short cycle, usually less than two seconds. Intermittent vibrations can be defined as continuously intermittent effects (such as drills) or continuously varying vibrations in intensity on the ground.

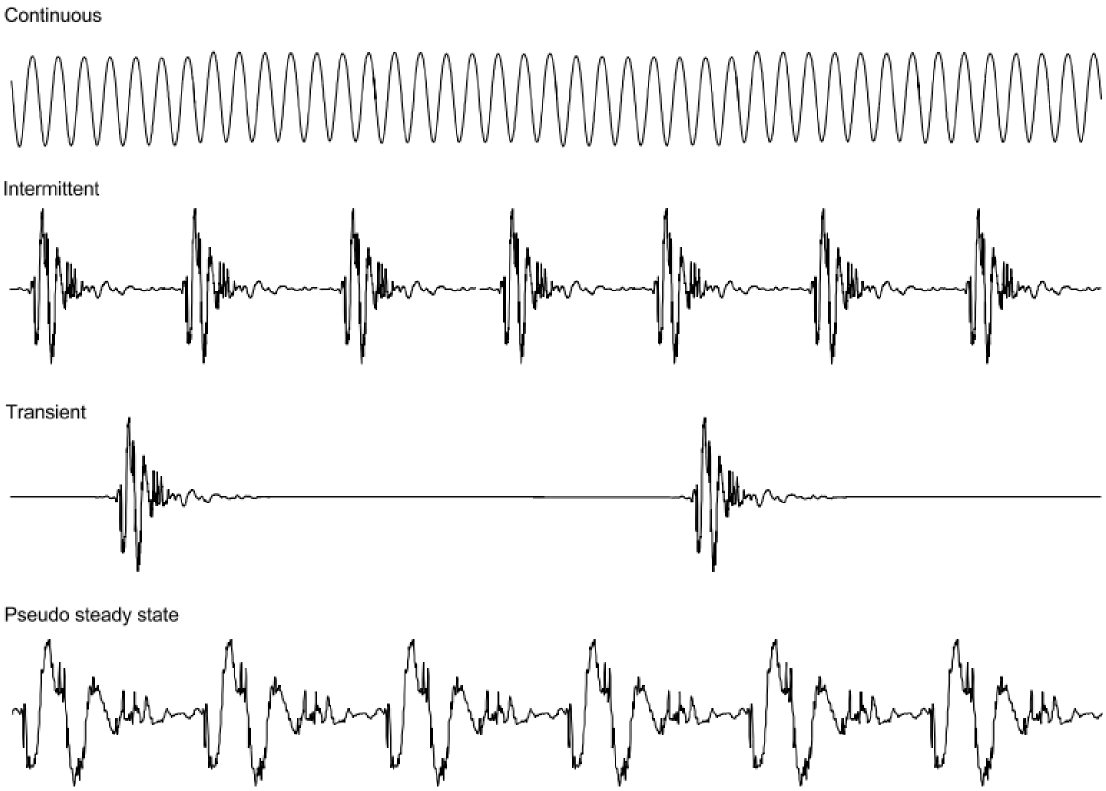

Figure 3.*Temporal variation of vibration [12]*

Ground vibration is an essential process of soil particles being transferred by stimulating force from one particle to another. Continuous motion from one particle to the next one leads to large-scale propagation affecting 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 structures directly. In this case, if frequency resonance occurs, it will cause damage to the structure.

Construction activities will create vibration and spread to the environment in the form of waves (waves propagate inside the ground), and surface waves transmitted along a surface (usually a surface above the ground). The most popular types of waves [13] are:

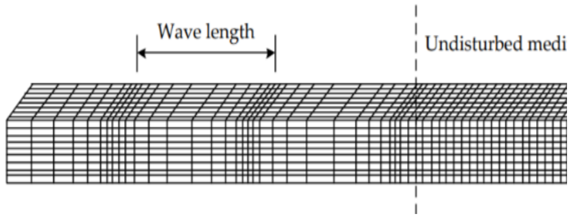

Figure 4. *Characteristics of P waves*

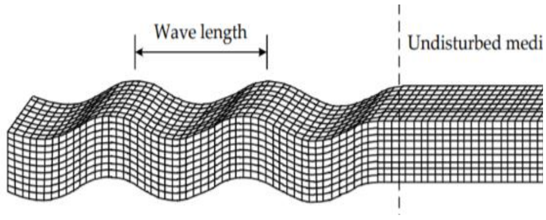

Figure 5. *Characteristics of S waves*

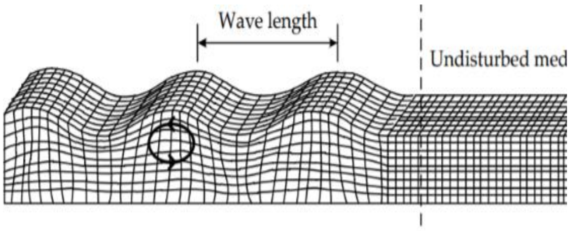

Figure 6. *Characteristics of R waves*

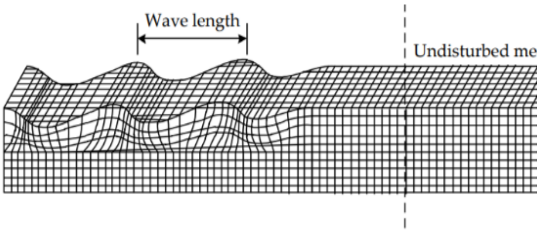

Figure 7. *Characteristics of L waves*

Most of the vibration assessment standards published by organizations in this day and age refer to some adverse threshold for human health and buildings still based mainly on the results of continuous vibration testing. On that basis, the vibrations can be assessed relied on two criteria: affecting people and affecting structures. In this work, we only focus on evaluating the effect of the roller on structures. In general, there are many construction activities causing vibrations in the process of constructing metro projects. However, in this research, the only vibration caused by the compaction of the roadbed from rollers is considered (with the most influential). Small sources of vibration are ignored, whereas large sources of vibration generated by other construction activities such as digging, driving piles were ceased temporarily to measure the vibration from the roller.

Soil compaction is one of the essential and indispensable works in construction, especially infrastructure construction. The process of soil compaction is the effect of instantaneous load and shock load. Under the effect of compacted load, the compacted soil layer generates stress - deformation waves and also causes ground vibrations.

With the advancement of machinery and equipment fabrication techniques and the higher requirement for compacting quality as well as the increase in the capacity and weight of the roller. Construction can improve compaction quality, increase compression layer thickness and speed up construction speed. However, this factor also possibly causes some negative phenomena such as ground shake, damages of surrounding buildings...

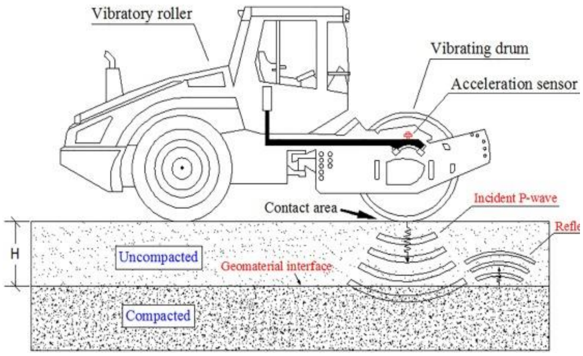

Figure 8. Principal components of a roller-compactor with smooth drum [14]

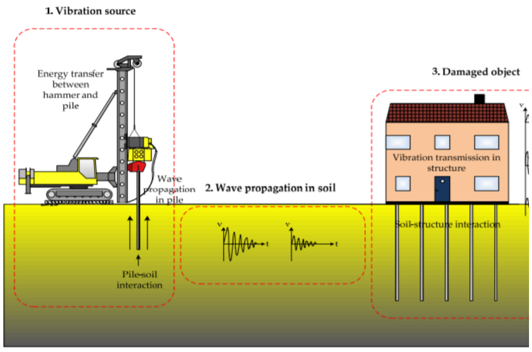

Figure 9. Vibration propagation process due to piling [1]

Furthermore, driving (vibrating) and lowering piles is also common construction work during the construction process, the implementation methods are very diverse generating different vibrations. To avoid negative effects and ensure safety, it is necessary to study the effects caused by the pile driving process, and its impacts on the neighboring structures. However, with the use of high-powered vibrating rollers, the vibrating process creates vibration waves that spread quickly from near to far on the ground surface. If necessary measures are not taken, the process of vibrating can lead to cracking of retaining walls, culverts, and bridges, affecting the normal life of surrounding residents, production conditions of industrial enterprises, or even threaten the safety of surrounding buildings. In order to protect the environment around the construction site and reduce damage to structures and surrounding buildings, it is necessary to study the propagation law of ground vibrations due to soil compression and reduce the effects of vibrating waves to surrounding structures.

In this work, measured and calculating results are compared with the values specified in [15]: QCVN 27:2010: national technical regulation on vibration issued by the ministry of natural resources and environment. This comparison provides the appropriate assessment of geological conditions and safety measures for the construction site.

Figure 10. Construction site – Ho Chi Minh City

To assess the impact of the construction operation on neighboring buildings and the surrounding environment, we conducted a measurement campaign to collect data at the site of metro line 1 construction project: Ben Thanh – Suoi Tien belonging to the Ho Chi Minh city urban railway line. Since the metro line 1 construction project is a key one located in the city center with a dense population, some requirements relating to construction progress, construction quality, etc... need to be complied with. In this case, contractors mobilized a large number of construction machinery such as rollers, excavators, bulldozers, ... operate at maximum work capacity. This exerts adverse effects on the surrounding environment, causes ground vibration, and inflicts some considerable damages.

To obtain ground vibration characteristics, two monitoring positions consisting of A1: Ben Thanh Station - 23/9 Park and A2: Ben Thanh Station - Ben Thanh Market are chosen. These two places are located in an inner-city with a high population density suffering the effect of vibration sources caused by the construction activities of the metro line 1 project.

To collect actual data at the construction site caused by the vibrating source of rollers compacting soil, we measured the vibration using the vibration intensity (dB). The equipment is selected based on technical requirements specified in TCVN 6963: 2001 [16] listed as below:

- Measurement frequency range: 1 Hz - 300 Hz (non-linearity £ = 10%)
- Acceleration: 0,005 m/s2 - 200m/s2
- The measuring equipment consists of:
- Sensor.
- Signal converter.
- Device for reading and recording measurement results.
- The chosen measuring device is the Rion Vibration Meter VM-83 with a measuring limit: 0.0001 to 1000m / s2; Frequency: 1Hz to 10kHz

Figure 11. *Vibration meter-Rion VM-83*

To obtain the most important information about the vibration behavior of the ground, it is necessary to analyze and select the most characteristic points. When measuring vibration on the ground, the sensors are attached on an iron pole with a diameter of 16 mm driven into the ground about 20-40 cm. The top of this iron pole must not protrude more than 2 cm above the ground.

The measurement time is 24 hours, the average acceleration value of the 10 largest ones of the 100 measured ones (each value measured for 5 seconds) is obtained. The results were extracted using the connection between a vibrator to a computer.

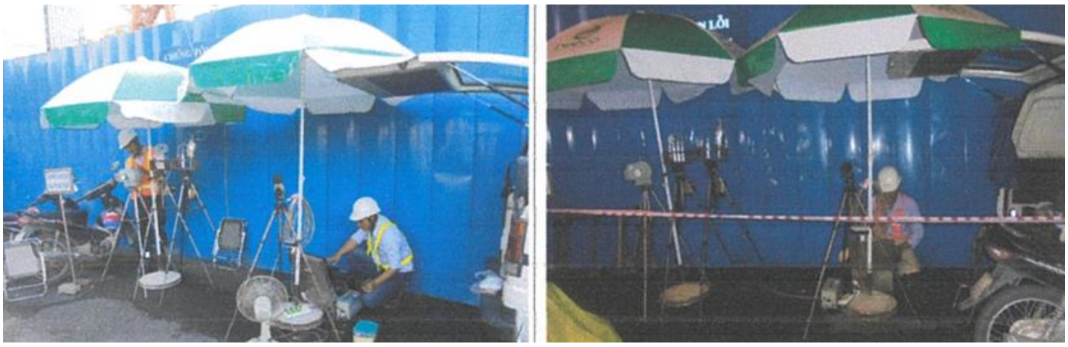

Figure 12. *Monitoring position A1: Ben Thanh Station - 23/9 Park*

Figure 13. *Monitoring position A2: Ben Thanh Station - Ben Thanh Market*

Ground vibrations are often described as the maximum particle velocity. The intensity of vibration at a point can be determined through three vibration parameters including displacement, velocity, and acceleration. In some standards, vibration velocity is commonly used to determine the intensity of the vibration calculated in decibels to distinguish it from the sound intensity [17]. The maximum vibration intensity during the measurement time can be calculated as follows:

$$L = maxL_i \leq [L] \tag{1}$$

In which:

$$\mathrm{L_i} = 20\log_{10}\frac{v_i}{v_{ref}} \qquad [VdB] \tag{2}$$

$$v_\mathrm{i} = \sqrt{\frac{1}{(t_2 - t_1)f_{SP}}\sum_n v_n^2} \qquad [m/s] \tag{3}$$

$$v_\mathrm{n} = \sqrt{v_{xn}^2 + v_{yn}^2} \qquad [m/s] \tag{4}$$

+ L is the highest vibration intensity;
+ $\mathrm{L_i}$ is the vibration intensity at interval *i* (1s);
+ $[L]$ is the standard limit of vibration intensity;
+ v_i is the average vibration velocity at interval *i* (1s);
+ v_{ref} is the reference vibration velocity, v_{ref}= 5.10^{-8}m/s [18];
+ t_1, t_2 is start/end calculation time v_i, t_2 - t_1=1s;

+ f_{SP} is the amount of calculated or measured velocity data per second;
+ v_{xn}, v_{yn}, v_n is the transverse, vertical vibration velocity and the total vibration velocity n^{th}.
+ L_e is the vibration intensity according to the catalog of equipment;

The calculated results and obtained measurement data are summarized and compared in Table 1:

Table 1. *Vibration intensity results*

Positions	**Time**	**Results (dB)**					**QCVN 27:2010/BTNMT (L_{10}) [19]**
		Ground	**L_{EQ}**	**L_{max}**	**L_{10}**	**L_{90}**	
A1	6:00 - 21:00	53.8	45.8	68.6	57.4	41.9	**75**
	21:00 - 6:00	50.7	44.7	68.3	55.2	40.6	**Ground Level (50.7)**
	6:00 - 21:00	55.3	44.3	67.2	55.4	40.7	**75**
	21:00 - 6:00	53.9	43.8	65.6	54.1	37.4	**Ground Level (53.9)**
A2	6:00 - 21:00	53.8	48.6	71.7	60.3	42.4	**75**
	21:00 - 6:00	50.7	46.5	69.1	58.9	41.2	**Ground Level (50.7)**
	6:00 - 21:00	55.3	46.1	68.4	57.6	42.5	**75**
	21:00 - 6:00	53.9	44.9	67.2	56.3	39.7	**Ground Level (53.9)**

Table 2. *Results of vibration acceleration level according to the measurements (Unit of error is %)*

Positions	**Comparison**	**Results (dB)**						**QCVN 27:2010/BTNMT (L10)**
		Ground	**6:00-9:00**	**9:00-12:00**	**12:00-15:00**	**15:00-18:00**	**18:00-21:00**	
A1	Measurement	53.8	53.7	60.0	52.8	65.8	63.2	**75**
	Calculation	54	53.9	60.2	53.1	66.1	63.8	
	Error	**0.37**	**0.39**	**0.31**	**0.55**	**0.46**	**0.93**	
	Measurement	50.7	51.9	56.1	67.8	62.0	61.9	**Ground Level (50.7)**
	Calculation	51	52.3	56.7	68.0	62.7	62.5	
	Error	**0.59**	**0.75**	**1.07**	**0.23**	**1.06**	**0.99**	
A2	Measurement	55.3	53.5	60.6	62.8	62.0	65.9	**75**
	Calculation	56	54.8	62.0	64.5	64.1	67.0	
	Error	**1.27**	**2.37**	**2.39**	**2.76**	**3.45**	**1.72**	
	Measurement	53.9	61.7	54.8	48.9	64.7	65.5	**Ground Level (53.9)**
	Calculation	55	63	56	50	66.4	68	
	Error	**2.04**	**2.18**	**2.21**	**2.31**	**2.68**	**3.79**	

From the obtained results of monitoring, measuring, and calculating, some considerations are given as follows:

All values of obtained vibration acceleration (L10) are higher than the vibration one of the background environment (approximately 1.1 to 1.3 times), even during working and at rest time. That proves that during the construction process, the implementation of the construction process, the operation of machines as well as equipment, along with the transportation of soil and rock, material to the construction site affects the vibration level of the ground in the construction site (specifically at the monitoring locations). The results show that vibration acceleration during working time in construction areas is almost higher than that during break time. Due to the sensitivity, the effects caused by vibration in a quiet environment (during break time (21h:06h)) are often stronger than during working hours (06h:21h). Based on the aforementioned conclusions, some solutions are proposed to reduce the negative effect of construction activities on neighboring buildings and the surrounding environment

- It is necessary to build programs to predict the law of vibration transmission due to the construction activities of metro projects exactly.

- Hence, the construction work should be underway during the daytime and other duties that have less impact on vibrations can conduct during the break time. This strategy possibly reduces the effect of construction work on the life of surrounding residents.

- To ensure safety and prevent damage to the building, the sources of vibration and vibration due to construction activities must not exceed the value in Table 3.

Table 3. *Permissible maximum value of vibration acceleration for construction activities [15]*

Order	Area	Time to apply during the day	Allowable vibration level (Vdb)
1	Special area	6:00 – 18:00	75
		18:00 – 6:00	Ground level
2	Normal area	6:00 – 18:00	75
		18:00 – 6:00	Ground level

In which:

– Special areas include areas within the fence of medical facilities, libraries, kindergartens, schools, churches, temples, pagodas and other areas with special regulations.

– Normal areas include apartment buildings, detached or detached houses, hotels, motels, administrative offices.

During working hours, although the results of vibration acceleration were higher than the baseline values, the results are still within the limits (75dB) of QCVN 27: 2010 / BTNMT. During the break time, although the results of vibration acceleration are higher than the ground environment vibration, acceleration values are mainly due to the impact of traffic activities outside the construction site. However, some measures should be adopted to minimize the effects of vibrations during this time, to ensure that the vibration acceleration level is within the allowable limits.

III. CONCLUSIONS

Construction activities often generate ground vibrations that can affect as well as damage buildings or affect residents in surrounding buildings. Therefore, the assessment of the possibility of damage to buildings and constructions due to many different sources, especially the construction of new structures is extremely vital. This paper analyses the effects of the construction operation of metro line 1 construction project: Ben Thanh – Suoi Tien on neighboring buildings and the surrounding environment. From the obtained results, some conclusions can be drawn as follows:

The ground vibration prediction method, unlike physical measurements, cannot describe vibrations in terms of their frequency components (frequency spectrum). Their output is therefore limited to the vibration amplitude, especially for the maximum particle velocity.

The results show that vibration acceleration during working time in construction areas are almost higher than those during break time.

All values of obtained vibration acceleration (L10) are higher than the vibration one of the background environment (approximately 1.1 to 1.3 times), even during working and at rest time.

The results of the paper can be used as a useful reference for consulting agencies, students, lecturers, and graduate students working in the field of structural health monitoring.

ACKNOWLEDGMENT

This research is funded by University of Transport and Communications (UTC) under grant number T2020-CT007TD.

References

[1]. *H Dang Trong*, Thesis Dang Trong Huy's master's, topic: "Research on the effects of vibrations in the construction of the Ben Thanh - Suoi Tien metro line", University of Transport and Communications – Campus II, Ho Chi Minh City, Viet Nam

[2]. Lyu, H.M., Shen, S.L., Zhou, A. and Yang, J., 2019. Perspectives for flood risk assessment and management for mega-city metro system. *Tunnelling and Underground Space Technology*, *84*, pp.31-44.

[3]. Roy, B. and Hugonnard, J.C., 1982. Ranking of suburban line extension projects on the Paris metro system by a multicriteria method. *Transportation Research Part A: General*, *16*(4), pp.301-312.

[4]. Lyu, H.M., Zhou, W.H., Shen, S.L. and Zhou, A.N., 2020. Inundation risk assessment of metro system using AHP and TFN-AHP in Shenzhen. *Sustainable Cities and Society*, *56*, p.102103.

[5]. Information on the Ho Chi Minh City urban railway route - line 1 –

https://en.wikipedia.org/wiki/Ho_Chi_Minh_City_Metro

[6]. Zhang, L., Skibniewski, M.J., Wu, X., Chen, Y. and Deng, Q., 2014. A probabilistic approach for safety risk analysis in metro construction. *Safety science*, *63*, pp.8-17.

[7]. Ding, L.Y. and Zhou, C., 2013. Development of web-based system for safety risk early warning in urban metro construction. *Automation in Construction*, *34*, pp.45-55.

[8]. Ozer, U., 2008. Environmental impacts of ground vibration induced by blasting at different rock units on the Kadikoy–Kartal metro tunnel. *Engineering Geology*, *100*(1-2), pp.82-90.

[9]. *Tran-Ngoc, H., Khatir, S., Le-Xuan, T., De Roeck, G., Bui-Tien, T. and Wahab, M.A.*, A novel machine-learning based on the global search techniques using vectorized data for damage detection in structures. International Journal of Engineering Science, 157, p.103376, 2020.

[10]. *Dang, H.V., Tran-Ngoc, H., Nguyen, T.V., Bui-Tien, T., De Roeck, G. and Nguyen, H.X*, Data-driven structural health monitoring using feature fusion and hybrid deep learning. IEEE Transactions on Automation Science and Engineering, 2020.

[11]. *Hoa, T.N., Khatir, S., De Roeck, G., Long, N.N., Thanh, B.T. and Wahab, M.A.*, An efficient approach for model updating of a large-scale cable-stayed bridge using ambient vibration measurements combined with a hybrid metaheuristic search algorithm. Smart Structures and Systems, 25(4), pp.487-499, 2020.

[12]. *D M Hiller and G, I Crabb*, Groundborne vibration caused by mechanised construction works, Prepared for Quality Services – Civil Engineering, Highways Agency, Transport research laboratory TRL report 429.

[13]. *PD Cenek and AJ Sutherland*, Ground vibration from road construction, Opus International Consultants Ltd, Central Laboratories; IR McIver, GREENBeing Consulting Engineers - New Zealand Transport Agency research report 485 (May 2012).

[14]. Analytical modeling of the stick-slip motion of an oscillation drum https://www.researchgate.net/figure/Principal-components-of-an-oscillation-roller-compactor-with-smooth-drum_fig1_334185603

[15]. QCVN 27:2010 - national technical regulation on vibration issued by the ministry of natural resources and environment

[16]. TCVN 6963:2001 - Vietnamese Standard TCVN 6963: 2001 on Vibration and concussion - Vibration caused by construction activities and industrial production - Measurement methods

[17]. FTA (2006), Transit Noise anFTA (bration Impact Assessment, Office of Planning and Environment - Federal Transit Administration.

[18]. СП 23-105-2004, Оценка вибрации при проектировании, строительстве и эксплуатации объектов метрополитена, Свод правил по проектированию и строительству.

[19]. QCVN 27:2010/BTNMT: National technical regulation on vibration