Recent Trends in Civil Engineering and Built Environment Vol. 4 No. 3 (2023) 263-270

RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

Study of Ground Vibration Generated by Train at Rail Curve

Brian Mclair Nicholas[1], **Felix Ling Ngee Leh**[1]*.

[1]Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Associate Professor, Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia

DOI: https://doi.org/10.30880/rtcebe.2023.04.03.028
Received 06 January 2022; Accepted 15 May 2023; Available online 31 December 2023

Abstract: A train is a type of rail transportation that consists of a group of connected vehicles that convey passengers or cargo along a railroad track. However, ground vibration produced by the train for some cases can be disturb the comfort of residents who live in a nearby area. There is a concern that the curve railway could generate higher level of ground vibration due to centrifugal force of the train movement to maneuver the curve. Hence it is necessary to carry out the study for the evaluation of train-induce ground vibration. This case study aimed to determine the ground vibration level of train at rail curve and compared it with straight rail. The finding of this study was aimed to compare the train induced ground vibration between curve rail and straight rail and the evaluation of the effect of train-induced ground vibration towards nearby residential area. The location of the case study was selected on along the Kluang-Gemas railway. Three accelerometer sensors for each Location 1 and Location 2 were set on straight and curve railways. For the soil investigation, Mackintosh Probe Test was carried out to know the bearing capacity of the soil. The ground vibration data obtained was evaluated using DOE (Department of Environment) guideline to make sure it is safe for residential nearby. The level of ground vibration of train at rail curve was obtained and it is known that the ground vibration at rail curve has a higher peak velocity compared to a straight rail and peak velocity result obtains for both Location 1 and Location 2 were comply with the DOE (Department of Environment) vibration and the environment control guideline. Hence the train-induced ground vibration is safe for human comfort as the peak velocity does not exceed the recommended limits for human response and annoyance from short term vibrations on the DOE guideline.

Keywords: Ground Vibration, Train, Rail Curve

Corresponding author: felix@uthm.edu.my

1. Introduction

In today's modern era, rail is one of the public transports used in Malaysia. It is due to easy to travel fast in different states and avoiding traffic congestion, especially in Kuala Lumpur. However, the movement of train can produce a certain amount of ground vibration, which can be harmful to the nearby area including human comfort and sleep quality if it is uncontrolled [1]. The need to reduce the amount of train-induced ground vibration which comply to DOE (Department of Environment) vibration limits and control in the environment guidelines is vital to reduce the effect towards nearby residential area. To determine the amount of ground vibration that produced by the train movement, a study was conducted at the Kluang-Gemas's railway, which involved in two different locations. Location 1 was focuses on curve rail while Location 2 focuses on straight rail. train movement that generates ground vibration level that may be disturb the comfort of residents who live nearby. In addition, there is a concern where rail curve may generate higher level of ground vibration due to centrifugal force of the train movement to maneuver the curve. Therefore, a comparison study is in need to evaluate the differences of ground vibration from rail curve and straight-line rail.

The aim of this study is to determine the ground vibration level of train at rail curve and straight rail, to assess the effect of rail geometry on the ground vibration and to evaluate the effect of train vibration on the residential area. This study was conducted at 1.35 km for Location 1 and 1.06 km for Location 2 from Kluang railway station, Johor. It focuses on the train-induced ground vibration on the rail curve, where the analysis result was compared with the straight rail. In addition, the analysis for straight and curve rail was evaluated based on the DOE (Department of Environment) vibration limits and control in the environment guidelines. The study was used DewesoftX software to obtain the train-induced ground vibration data and analyse based on the peak velocity for each accelerometer sensor. For the soil properties, an investigation has been conducted using Mackintosh Probe Test to identify the soil layer based on the bearing capacity.

2. Ground Vibration on Railways

An uncontrolled vibration on the railways can cause buildings to shake and rumbling sounds can be heard. However, there might be several factors that can contribute to the ground vibration in railways and how it impacts towards building and human health.

2.1 Source of Train-Induced Ground Vibration

One of the source rail ground vibrations might be is the speed of the train. A different model of train has its own different speed. For the train model CDK8E, which currently used by KTMB on Northern Shuttle train from Kluang to Gemas Rail Station, the maximum speed is 140 km/h. This can be expected that the higher the speed of the train, the higher frequencies of the ground vibration [2]. As for the diesel electric locomotive, it has an average speed compared to a high-speed train. Moreover, the vibration may be occurred from the unevenness neither wheel or the rail running surface move vertically relative to another. As a result, the dynamic forces that are generated from the wheel or rail contact with the running surface can lead to wave propagation in the ground [3].

2.2 The Effect of Soil Properties Towards Ground Vibration

The strength of ground vibration can be affected by soil properties. It is known that the ground vibration produced by the movement of train and then it will transmit to the soil, where it formed different type of waves but mostly on Rayleigh waves. Because the subsoil beneath the ballast bed is commonly made up of several layers (inhomogeneous), the soil's elasticity might vary throughout the track. As a result, the vehicle and track, as well as the track substructure and the earth, interact and vibrate at a variety of resonance frequencies. For some vibration in soil that produced Rayleigh wavelengths, a higher shear wave velocity may cause vibration amplification due to stable soil resonances [2]. In addition, vibration propagation from the ground into the building is greatly influenced by the interaction of soil and structure. The moisture content of the soil might be affected if the subgrade of the railways has a high amount of rainfall in every moth which will affect the mechanical behaviour in the field and changes in ground vibration level [4].

The soil properties can be identified based on different type of test. One of the common tests that have been used and cost savings was Mackintosh Probe Test. The Mackintosh Probe is a portable and lightweight penetrometer [5]. When the depth of exploration is moderate and the soils under inquiry are soft or loose, it is a much faster and less expensive tool than boring equipment.

3. Case Study Location

This study started with a site selection, where Kluang-Gemas railway was selected. There were two phases in order to complete the case study. From Phase 1, two separate test was conducted, which is Mackintosh probe test and train-induced ground vibration data collection. A train-induced ground vibration contains two field tests, which located at the curve rail and straight rail. As for determining soil properties, only one location was selected to performed Mackintosh probe test, which is on the Location 1, where accelerometer sensors were placed. After completed Phase 1, the data analysis was performed on Phase 2, which is determining the soil bearing capacity and the DewesoftX data result. This contains the graph, data tables which later evaluate based on DOE (Department of Environment) vibration limits and control in the environment guideline.

A case study for the data location has been set on the Kluang-Gemas Johor railway, which is near the Kluang Railway Station. Each station is set which on straight and curve rail track. The distance between Location and Location 2 as shown in Figure 1 below are not far from each other, which is 284.41 m. The operational hours for the Kluang Railway Station are 7 days from 6am to 6pm. In this case study, there are 2 locations with 3 accelerometer sensors in each location.

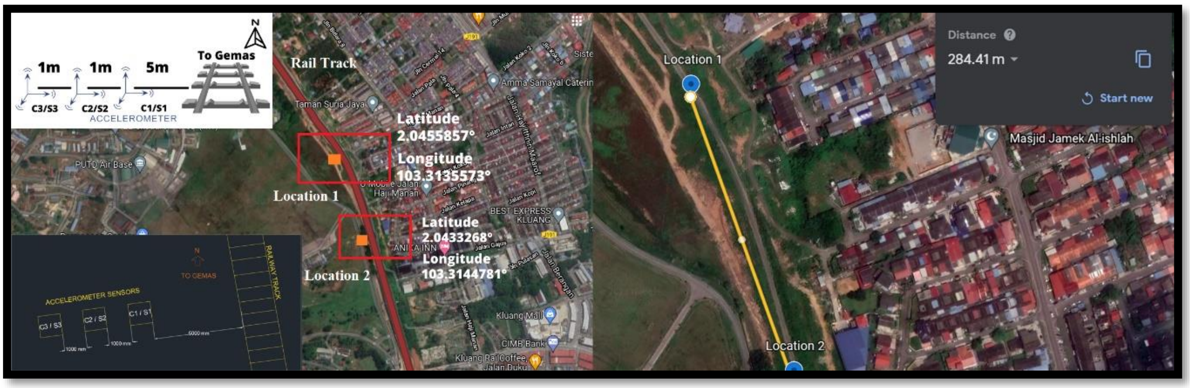

Figure 1: Case study location.

4. Materials and Methods

A case study for the data location has been set on the Kluang-Gemas Johor railway, which is near the Kluang Railway Station. Each station is set which on straight and curve rail track. There are 2 locations with 3 accelerometer sensors in each location. In this case, there are 3 sensors for each set of data collection. The train movement is from south to the north. There were 3 accelerometer sensors was placed in Location 1 and 2 with 5 meters for the first sensors followed by 6 meter and 7 meters from the railway for the second and third sensors on the x-axis. The total sample size for this case study is 6 ground vibration sample data was collected, which 3 ground vibration data sample for each location. The model for train diesel-electric locomotive is CDK8E with maximum speed of 140 km/h and weight about 120t. The wheel diameter for this model is 965 mm and the suitable track gauge is 1000mm [6]. For Location 1 is located on the rail curve. There are also 3 accelerometer sensors which label as C1, C2, and C3. C1 was placed 5 meters from the rail track while C2 is 6 meter and C3 is 7 meters from the rail track on the x axis.

The condition of Location 2 is also near the residential area and at a straight rail track. The setup of accelerometer sensor is the same as Location 1, where 3 accelerometer sensors was setup and labelled as S1, S2, and S3. S1 was placed 5 meters from the rail track while S2 is 6 meter and S3 is 7 meters from the rail track on the x-axis. Figure 2 below shows the sample setup for both Location 1 and Location 2.

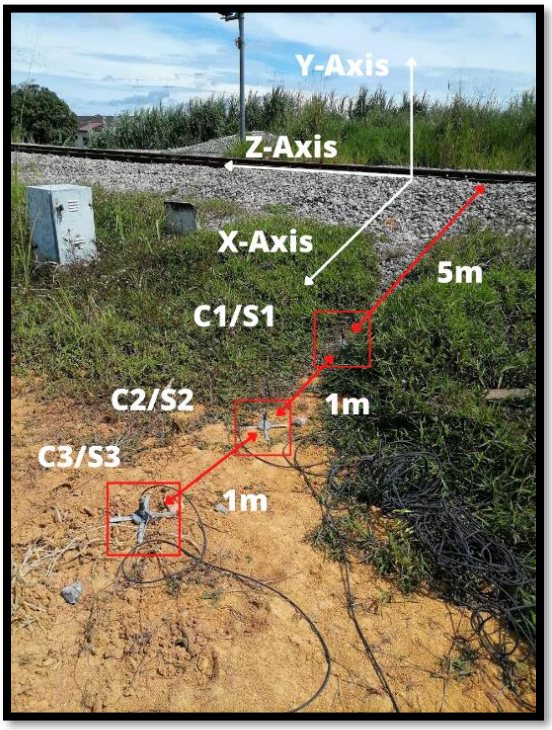

Figure 2: Sample setup of accelerometer sensor on the x-axis for Location 1 and 2.

4.1 Materials

There are different types of equipment were used to collect ground vibration data. This equipment was used on both Location 1 and Location 2. The equipment is listed below:

- Data Acquisition System Sirius-M D00C034D67.
- Accelerometer sensors ICP 603C01.
- Cable
- Plate
- DewesoftX

For Mackintosh Probe Test, there are several equipment is used. The basic hardware tools that are used is hammer, wrench and marking pen to mark the depth of the penetration on the steel rod. Probe Mackintosh Tools consists of different tools inside the box including penetration steel rod, coupling, and lifting which function as for soil investigation. There are two types of penetration cone, which can be divided based on their angle. For Mackintosh probe is using 30^{o} angle while 60^{o} is for JKR probe [7]. In this case study, 60^{o} angle penetration cone JKR probe was used.

4.2 Method

In this study, the methods that was used divided into two parts, which is ground vibration data collection and Mackintosh probe test.

(a) Ground Vibration Data Collection

For data collection of ground vibration, three acceleration sensors are set and installed in each point in the x-axis with 5 meters on first sensor, 6 meters on second sensor and 7 meters for the third sensor from the railway. The first location was be set on the curve railways while the second location was set on the straight line. Each sensor was marked according to the setup location. The train moves from south to the north, which move parallel to the z-axis. In this case, only the train that carry passengers is taken into measure while freight train is not included due to different type of load that train was carry. Before the accelerometer sensor setup, the ground surface was cleared from any obstacle and the ground vibration data taken for 5 seconds for Location 1 and Location 2. The train speed was measured using speed gun, which was 31 km/h for both Location 1 and 2.

This to measure the speed of train, how it will affect the ground vibration. 2 set of data was taken from 2 different train that pass by the sensor zone. The 3 sensors were placed in each location on the x-axis. The data was collected, and the graph was observed using computer. All step above is repeated for the data analysis of on the next location. The peak velocity result obtained from DewesoftX was evaluated by using DOE (Department of Environment) vibration limits and control in the environment guideline.

(b) Mackintosh Probe Test

To start the testing process, penetration cone angle 60° as shown in Figure 3 below was attached to the bottom of a steel rod and hammer on top. On the point to be tested, the steel rod was aligned parallel to the ground surface and mark every 0.3m (1 feet) length of the steel rod with a chalk. The hammer was lifted to its highest point and then was released, and the number of blows is counted on how many it takes for the rod to penetrate 0.3m. In the Mackintosh Probe test form, the number of blows is recorded for every 0.3m penetration. The hammer set was recorded and, in the final 0.3m, a new steel rod was connected on top of the existing rod. For every 0.3m interval, the rod was marked repeatedly. Continue blowing with the hammer and repeat the operation. Because the soil has a high carrying capacity, the blows was stopped after the depth of penetration reaches 3m. The data was obtained based on the depth of penetration and number of blows. In addition, bearing capacity obtained from the data was used to determined the type of soil components for each soil layer.

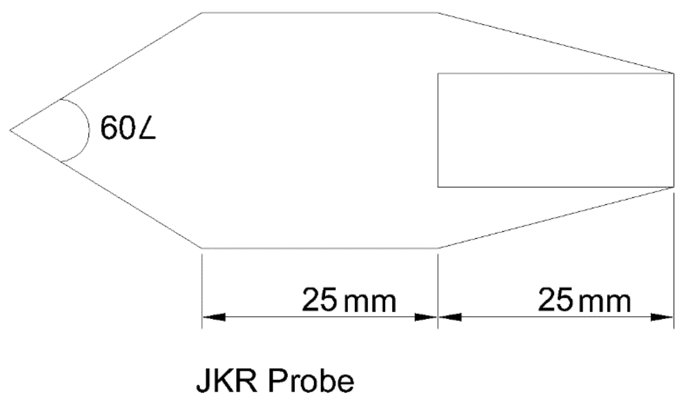

Figure 3: JKR probe penetration cone angle.

5. Results and Discussion

Based on the method given, there were two types of result obtained on the case study location, which is Mackintosh probe test result and train-induced ground vibration result. As for train-induced ground vibration result, it consists of two locations, which is on the rail curve and straight rail.

5.1 Mackintosh Probe Test Result

Based on the result from Probe Mackintosh test, the bearing capacity was determined based on the JKR Mackintosh Probe test graph that has been given. The number of no. of blows was used to estimate the bearing capacity (kN/m2). The underground soil at the test site can be broadly divided into three layers based on the number of blows.

Table 1: Mackintosh Probe test data result.

Depth (m)	No. of Blows	Bearing Capacity (kN/m^2)	Average Bearing Capacity (kN/m^2)	Soil Layer
0.3	24	60	**73**	Soft clays and silts
0.6	33	85		
0.9	60	165	**234**	Stiff Clay
1.2	86	310		
1.5	62	170		
1.8	69	200		
2.1	88	325		
2.4	70	285	**326**	Very stiff boulder clays and hard clays
2.7	76	320		
3.0	72	343		
3.3	78	355		

Based on the bearing capacity obtained from Probe Mackintosh Test, the type of soil properties was analyzed according to the depth and number of blows. By referring to BS 8004:1986, the bearing capacity is predicted as a very soft clays and silt on the first layer, while stiff clays on the second and very stiff boulder clays and hard clays third layer [9].

5.2 Train-Induced Ground Vibration Result

Based on the ground vibration result, there are 2 locations where the data has been taken, which are Location 1 on the rail curve and Location 2 on the straight rail. For Location 1 and Location 2, the speed of the train recorded were 31 km/h. The result obtained are from combination of 3 accelerometer sensor for each location. The peak velocity ground vibration from the result of each location was taken and compared to the Department of Environment (DOE) and the test result were recorded for a duration of 5 seconds.

Table 2: Overall peak velocity result and type of curve for both location 1 and location 2.

Data	Accelerometer	Distance From Rail Track (m)	Speed (Km/h)	Peak Velocity (mm/s)
1	C1	5	31	0.3
2	C2	6	31	0.21
3	C3	7	31	0.19
4	S1	5	31	0.41
5	S2	6	31	0.26
6	S3	7	31	0.29

5.3 Discussions

The distance between Location 1 and Location 2 is not far because it is in the curve vicinity, only 1 point of Mackintosh Probe test was taken, which is in the Location 1. Even though they are very close in vicinity, however this is not able to be proof that the soil condition is exactly the same. From Mackintosh Probe test result that has been obtained, there are three layers of soil. Based on BS8004, the bearing capacity of soil on the first layer was predicted as very soft clays and silts while stiff clays on the second and very stiff boulder clays and hard clays on the third layer. For the ground vibration are mostly occurred on the first layer of soil, which is predicted as Rayleigh waves or called as surface waves. The Rayleigh waves mostly produced by railway trains and the lower-frequency energy arrives earlier in the waveform. Seismic sources near the surface tend to excite strong Rayleigh waves, whereas sources deep in the Earth excite only weak Rayleigh waves [8].

The speed of train recorded are the same, which is 31 Km/h for both locations because of gentle curve and does not steep. Moreover, the train has 3 passenger cabin, 1 driver cabin and 1 engine cabin. The peak velocity for both location 1 and location 2, the first accelerometer sensor, which is C1 and S1 has recorded the highest peak velocity compared to the second and third accelerometer sensor. In addition, the data result on Table 2 shows that the straight rail has highest peak velocity than curve rail. For location 2, accelerometer sensor for S2 and S3 show the differences that not significant.

Based on the DOE (Department of Environment) vibration limits and control in the environment, the ground vibration must not exceed curve 16 for residential area. This is because there is a residential area near the Location 1 and Location 2. Based on the result that has been obtained, it was predicted that most of the peak velocity obtained from both locations does not exceed curve 4.

Conclusion

This case study has met the objectives because the level of ground vibration of train at rail curve and straight rail has been obtained. Moreover, based on the data obtained, the result given has met the DOE (Department of Environment) vibration and the environment control guideline specifically in residential area case. To conclude this study, Location 2 which is on the straight rail has the highest peak velocity compared to Location 1 at the rail curve. Although the result is vary for each sensors in both Location 1 and Location 2, it was predicted that all peak velocity result obtained were comply with the DOE (Department of Environment) vibration and the environment control guideline. In addition, the train-induced ground vibration is safe for human comfort as the peak velocity does not exceed the recommended limits for human response and annoyance from short term vibrations on the DOE guideline. To improve the case study, there are several recommendations that can be considered. A soil test must conduct at both Location 1 and Location 2 so that the soil condition can be identified. In addition, a data can be Performed by taking simultaneously on the horizontal axis (z-axis) and vertical axis (x-axis) to obtain more accurate data. However, these required a 2 Data acquisition software because each Data acquisition software consists of 4 channels only and 3 accelerometer sensors needed for each axis. An interview with the authorities such as KTMB (Keretapi Tanah Melayu Berhad) is recommended to know the components of train and railway track. Moreover, referring previous research (if any) by the authorities on the area of case study is needed for comparison. An interview with the local resident on the nearby case study location is also recommended to identify the level of disturbance and annoyance of ground vibration towards the residential nearby.

Acknowledgement

A big thanks to Faculty of Civil Engineering and Built Environment administration office, KTMB (Keretapi Tanah Melayu Berhad) for their kindess to share thoughts, granted permission to do the research work and monitoring througout the fieldworks. The authors would like to express gratitude to UTHM Geology Laboratory for giving permission to access all the equipment needed for the research work.

References

[1] I. Croy, M. G. Smith, and K. P. Waye. May 2013. Effects of train noise and vibration on human heart rate during sleep: An experimental study. Bmj Open, 3(5), e002655.

[2] W. Zhai, K. Wei, X. Song, & M. Shao, May 2015. Experimental investigation into ground vibrations induced by very high speed trains on a non-ballasted track. Soil Dynamics and Earthquake Engineering, 72, 24-36.

[3] E. Ntotsios, D. Thompson, & M. Hussein, August 2017. The effect of track load correlation on ground-borne vibration from railways. Journal of Sound and Vibration, 402, 142-163.

[4] C. Zou, Y. Wang, & Z. Tao, January 2020. Train-Induced Building Vibration and Radiated Noise by Considering Soil Properties. Sustainability, 12(3), 937.

[5] S. M. S. I. B. Idid, P. N. B. A. Rahim, M. A. S. B. Suhaimi, A. M. B. Zambri, & I. A. B. Ismail, February 2020. The New Evolution Mackintosh Probe (NEMP). Institutional Repository. Politeknik Sultan Salahuddin Abdul Aziz Shah, Selangor.

[6] Zacliu. (2010). CKD8E Diesel-electric Locomotive (Exported to Malaysia), Retrieved January, 5, 2022, from http://www.zacliu.com/20101104/ckd8e/

[7] M. F. Yusof, M. N. F. Abd Khalid, S. A. A. Tajudin, A. Madun, & M. H. Z. Abidin, January 2017. Correlation of JKR Probe with undrained Shear strength. In MATEC web of conferences (Vol. 103, p. 07009). EDP Sciences.

[8] British Standard, B. S. CP 8004 (1986), Code of Practice for Foundations. British Standard Institution, London, UK.

[9] C. J. Ammon, A. A. Velasco, T. Lay, & T. C. Wallace, October 2020. Foundations of Modern Global Seismology. Academic Press.