MEASUREMENT OF GROUND VIBRATION INDUCED BY A MOVING VEHICLE AT BRIDGE APPROACHES

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ABSTRACT

This study was conducted to investigate the ground vibration induced by a vehicle at the bridge approach in Batu Pahat, Johor. This study also to specify and illustrate the vibration value based on identifying the influence class of vehicle, the speed of the vehicle and a zone of the vehicle at bridge approach which is the vehicle through to the bridge (inward) and out from the bridge (outward). The result of this study indicates that the vibration value is more significant by all the variables. In addition to these results, a description of the measurement technique, field data collection, and procedures are presented. The study shows potential to provide and improve the knowledge towards the importance of the vehicle loading of specific evaluation.

Key words: Bridge approach, ground vibration, peak particle velocity, vehicle loading.

INTRODUCTION

Due to the growing need for regional development, an engineer faces a challenge to discover a secure method to build transport infrastructure on soft soils (Rahman et al., 2019; Mohamad et al., 2016; Zainorabidin et al., 2015). The settlement of soft soil foundation has turned out to be one of the difficult circumstances to be noticed for foundation design with the fast growth of infrastructure and building construction. In terms of geotechnical properties, soft soil is well known for its low bearing capacity, high water content, high differential settlement, long term settlement and not able to sustain external loads without having large deformation (Rahman et al., 2019; Huat and Ali, 1993). Stability, deformations and time required for consolidation are the major concerns in the design and construction over soft soil. Therefore, it may need improvement to avoid excessive settlement and prevent stability failure. Meanwhile, when an infrastructure like road embankment and bridge approach used to be constructed over soft soil, there is a surcharge or an increase of stress including the strain or settlement. If the surcharge load due to filling and construction is excessive near the ultimate bearing capacity of the supporting soft ground, immoderate yield or plastic deformation in vertical and lateral direction of the soft ground will occur followed through tension crack, deep seated rotational slip when massive and large deformation occurs. According to this situation, road users will feel uncomfortable, can be dangerous and create traffic congestion because users suddenly had to reduce speed of the vehicle while crossing the bridge (Hassona et al., 2017; Mahmood et.al , 2014). The settlement at the end of a bridge close to the interface between the abutment and the embankment is a constant issue for road organizations (Rahman et al., 2019; Hassona et al., 2017; Zhang et al., 2017). This weakness which would lead to a series of negative effects, such as damage to vehicle, structure, public perception of the state infrastructure, maintenance cost, traffic delays and the most severe cases crash related to injuries and death. There are several reasons caused of bridge approach settlement has been reviewed by other researchers before and one of the problems is a difference between the height of the bridge and road on the connection. A review of previous research indicated numerous potential causes of bridge approach distress and indicating that the bridge approach settlement is largely a site specific problem (Hassona et al., 2018; Zhang et al., 2017; Chen & Abu Farsakh, 2016; Rose et al., 2015; Masirin & Zain, 2013; Puppala et al., 2009; Shen et al., 2007; Duppont & Allen, 2002).

The objective of this study is to determine and establish field investigation method to analyses influence of vibration from vehicle loading at bridge approaches. From the geotechnical dynamical engineering point of view, this vibration could be classified as a repetitive cyclic loading. The aim of this study is to investigate the influence and effect of vehicle loading to the settlement at bridge approaches. A higher level of vibration may not be acceptable to the bridge approach and may have an effect such as surface cracking, bumpy, pothole and differential settlement. In this study, researcher focus on the influence of vibration from vehicle loading due to settlement effect on bridge approach.

Measurement equipment with a portable vibration measurement system with high sensitivity triaxial ICP accelerometer used to investigate the effect of vibration from vehicle loading at bridge approaches by a certain distance set at the start of the research.

The vibration amplitude, can be measure in term of displacement (mm), velocity (mm/s), or acceleration (mm/s^2). From (Dowding, 1996), these equations (a) to (c) can be expressed the relationship between the vibration amplitude.

$$Displacement, u = \int \dot{u}\, dt \quad \text{(a)}$$

$$Particle\ Velocity, \dot{u} = \frac{du}{dt} = \int \ddot{u}\, dt \quad \text{(b)}$$

$$Acceleration, \ddot{u} = \frac{d\dot{u}}{dt} \quad \text{(c)}$$

As vibration occurs in a source, a seismic wave travel causing soil and rock particles move to back and forth over very small distances. This is known as particle velocity. When there is vibration each particle has a velocity and maximum velocity is referred to as the peak particle velocity. According to Connolly et al., 2015 and Hu et al., 2019, there are three most commonly used metrics for assessing vibration levels which are velocity decibels (VdB), vibration dose value (VDV) and Peak Particle Velocity (PPV). PPV is defined in the following equation (d) (Dowding, 1996 and Mohammad et al., 2018)

$$PPV = \sqrt{PV_x^2 + PV_y^2 + PV_z^2} \quad (4)$$

The particle by most is to use the reading of the peak particle velocity as the standard for measuring the intensity of the ground vibration. Mohammad et al., 2018, Kouroussis et al., 2014, and Mclver et al., 2012 had mentioned for ground vibration surveillance, peak particle velocity (PPV) is frequently used. PPV is also the normal control and disaster prevention measurement method that is normally used in building vibration control or vibration emissions owing to transport in several of recent regulations and guidelines (Mohammad et al., 2018; Bsi (2014); DOE Malaysia (2007). Ultimately, the report from vibration monitors prove helpful in demonstrating whether vibration is great enough to cause concern to bridge approach. The amplitude of the vibration additionally can be used with the guidelines for vibration control (Mohammad et al., 2018; Chik et al., 2013). The ground-borne vibration is measured in the PPV term, which refers to the vector sum of the peak vibration element (Mohammad et al., 2018; Rockhill et al.,2003; Athanasopoulos et al., 2000). It is now preferable for researchers to use the Piezoelectric (ICP) accelerometer for field surveillance or laboratory testing (Mohammad et al., 2018; Santos et al., 2016; Coulier et al., 2015; Adamo et al., 2014; Garinei et al., 2014).

This study focused on the bridge approach in Batu Pahat, Johor and as the test were conducted in the field, a durable and high resistance measuring equipment was needed to be used under hot weather for long duration. Existing laboratory vibration measuring tool are very sensitive specially to heat and dust. Therefore, the capability of each component was studied and tested before proceed to the next stages. Besides that, the testing and evaluation on the site are conducted by a portable vibration measurement system with high sensitivity triaxial ICP accelerometer which is available in uniaxial and triaxial, in compliance to Bsi (2014) and DOE Malaysia (2007). The knowledge of the bridge approach condition is essential as it enables designers to understand the response of the soil when loaded with vehicles and presentable suggestion for proper engineering solutions to overcome the problem. In order, rehabilitation work to be done immediately to avoid the worse to the road users, the vehicle and structure of the bridge itself.

MATERIAL AND METHOD

This study starts with preliminary study, that is important to find the appropriate method for obtaining relevant data. The method used in this study is to obtain the vibration value of the vehicle through the road and bridge that is observed base on the type of vehicle, speed and area zone that the vehicle passes by using sensor called a triaxial ICP accelerometer. Then, the computer software DEWE Soft X3 will be used to process, record and store the ground vibration data. With the single integration functionality of this software, conversion of raw acceleration data will be processed real time to particle velocity data with x-axis, y-axis, z-axis and also PPV. The propagation velocity is the velocity the wave passes through the cork, while the particle velocity is the velocity with cork moves up and down. A wave propagates faster by a hard, dense material than by a soft, flexible material. At the initial stage, the location of the study will be diversified to see and record whether there is a difference, or similarity, between the locations involved and at the same time can improve the skills in the use of tools and ways to deal with problems that occur in the tools. The vibration data were measured in time-domain using the particle velocity (mm/s) as the main unit for the vibration amplitude.

INSTRUMENTATION

Once the equipment is provided, preferably the measurement should be done to retrieve the actual data for further analysis. Accordingly, careful planning needs to be done before the field test to obtain the finest data. Therefore, in order to ensure that the experimental journey can run smoothly, a guide has been made as shown in Figure 1. This is a general diagram of method for selected locations and it will be used as a general guide for location that has been selected in this study. Following by Figure 2 (a) and (b), shows the zone setting for vehicle data through the bridge approach area at the study location in the direction before and after the bridge.

Figure 1: Location setting at bridge approaches

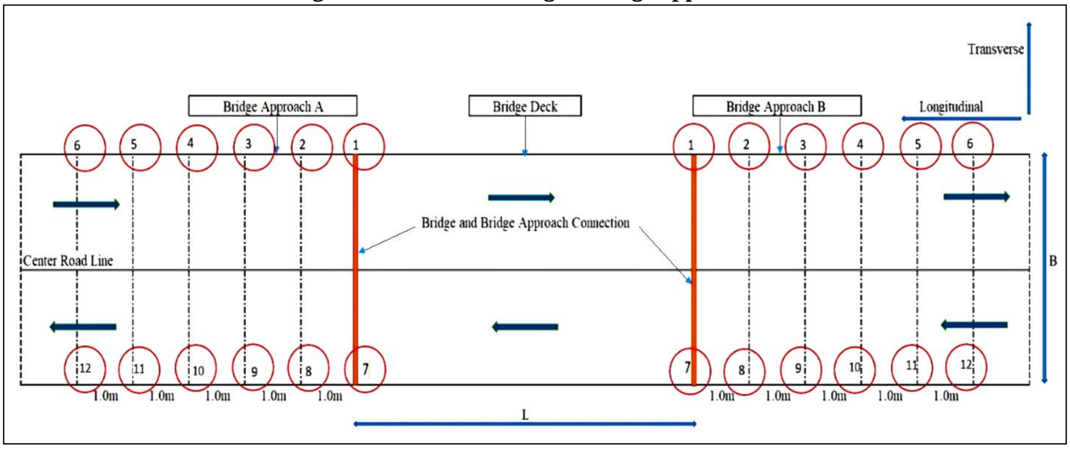
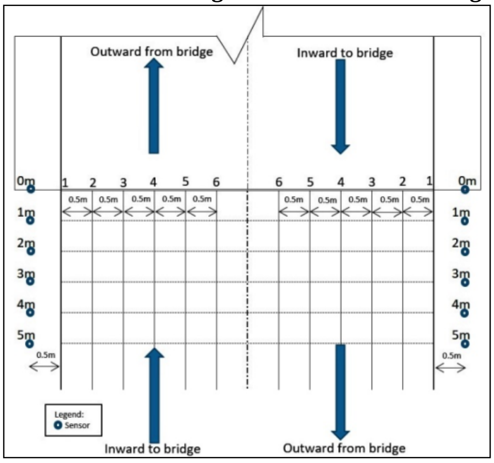
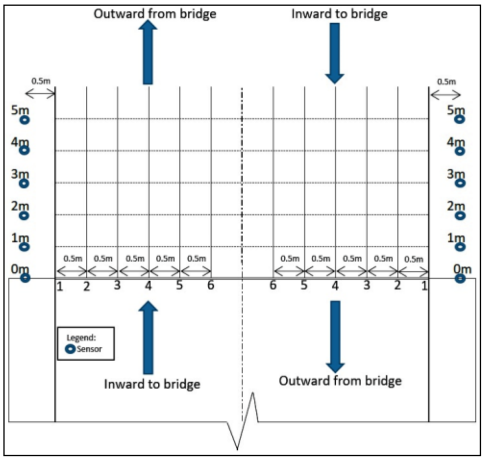


Figure 2: Zone of measuring vibration at bridge approaches



(a) Bridge Approach A (BAA)



(b) Bridge Approach B (BAB)

EQUIPMENT SETUP AND FIELD TESTING LOCATION

There are three main components integrated together to measure vibration from the ground surface, namely; ICP accelerometer sensor, data acquisition module, and portable computer as shown in Figure 3 and Figure 4. The field test was conducted on soft soil area in Batu Pahat, Johor at bridge Km 0.4 Jalan Parit Karjo (J109), as shown in Figure 5.

Figure 3: Testing equipment; (a) Data acquisition module 4 channel; (b) triaxial ICP accelerometer; (c) 4 pin BNC cable

Figure 4: Testing equipment arrangement; (a) Data acquisition module 4 channel; (b) Portable computer; (c) Triaxial ICP accelerometer

Figure 5: Site location at Bridge Km 0.4 Jalan Parit Karjo, Batu Pahat, Johor (GPS Coordinate 1.845228, 103.065027)

TESTING PROCEDURE

Prior to testing, the bridge approach should be measured and marked at a distance of 0.5m interval which is shown in Figure 6. This is important in the process of vehicle observation through which this research area is located within a zone that has been marked so that the data being polished is more accurate. The purpose is to obtain the vibration amplitude of vehicle passing through the designated zones. For data collection and observation, the triaxial accelerometer sensor is set up a distance 0.5m from the road. For the observation of various types and size of the vehicle, it is based on Class I, II, III and IV as shown in Table 1. Observed data are based on three (3) variables that are speed, vehicle class, and zone travelled by the vehicle. The speed and class of vehicles recorded is to see if it has an impact to the bridge approach. Fig.6 shows the bridge approach area which has been measured and marked based on distance from bridge connection as well as a vehicle route zone. In this study, the focus is on the data observation for the vehicle Class II, III and IV.

Figure 6: Bridge approach measured by sensor location and zone of the vehicle

Table 1: Classification of vehicles

Vehicle Class	Type of Vehicle
Class I	Motorcycles
Class II	Cars
Class III	SUV, Van, MPV, Small lorries (6 tons and less)
Class IV	Bus, Big lorries (more than 6 tons)

RESULT AND DISCUSSION

DOMINANT ZONE

To further execute an analysis, the result of the amount of data obtained in BAA and BAB, it is found the percentage of vehicle through zone 2 and zone 3 is higher than zone 1 and zone 4. This can be explained more by referring to Table 2. Therefore, the zone with most percentage of the vehicle through, which is from zone 2 and zone 3 will be used for further reviews and analysis.

Table 2: Percentage (%) of vehicles passing by zone

Sensor Location	BAA				BAB			
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 1	Zone 2	Zone 3	Zone 4
BC[D]	12.00	48.00	32.00	8.00	3.33	36.67	53.33	6.67
BC[R]	10.53	26.32	63.16	0.00	6.67	13.33	76.67	3.33
1m	10.53	57.89	26.32	5.26	0.00	43.30	56.70	0.00
2m	0.00	57.89	31.58	10.53	0.00	33.33	63.34	3.33
3m	3.40	34.5	58.60	3.40	0.00	36.70	60.00	3.30
4m	7.40	66.7	22.20	3.70	3.30	36.70	53.30	6.70
5m	4.00	44.00	48.00	4.00	0.00	23.30	66.70	10.00

INFLUENCE BY VEHICLE SPEED

As shown in Table 3, it is found that vehicle speed affects the value of PPV. By referring to the Table 3 at sensor location BC [D] at zone 2 (BAA), it is found when vehicle speed increased by 18% of speed from 36.46 km/h to 43.07 km/h, then the value of PPV increased to 73.40 mm/s (109.30%). Overall, the value of PPV increased when vehicle speed increased. At the same sensor location BC [D] at zone 3 (BAA), the value of PPV increased to 45.60 mm/s from 19.53 mm/s when vehicle speed increased from 30.86 km/h to 39.71 km/h. At sensor location BC [D] at zone 2 (BAB), it is found when vehicle speed increased from 26.46 km/h to 34.94 km/h, then the value of PPV increased 0.62 mm/s to 1.82 mm/s (193.50%). At the same sensor location BC [D] at zone 3 (BAB), the value of PPV increased to 0.80 mm/s from 0.64 mm/s when vehicle speed increased from 30.61 km/h to 37.21 km/h. The conclusion of this analysis of influence of vehicle speed, the PPV value of BAA is higher than BAB.

Table 3: PPV value at Zone 2 and Zone 3

Sensor Location	Vehicle Class	BAA Zone 2 Speed (km/h)	PPV (mm/s)	Zone 3 Speed (km/h)	PPV (mm/s)	BAB Zone 2 Speed (km/h)	PPV (mm/s)	Zone 3 Speed (km/h)	PPV (mm/s)
BC[D]	III	36.46	35.07	30.86	19.53	26.46	0.62	30.61	0.64
		43.07	73.40	39.71	45.60	34.94	1.82	37.21	0.80
BC[R]	III	33.54	3.28	38.74	3.33	26.55	0.62	29.89	0.39
		45.51	4.12	49.67	9.04	47.42	1.16	34.27	0.76
1m	III	45.26	1.07	37.03	1.23	25.52	0.67	24.03	0.45
		50.02	1.78	47.36	2.06	51.70	1.16	32.00	0.52
2m	III	31.89	0.87	39.01	0.50	31.59	0.55	31.27	0.42
		35.64	1.12	43.86	1.42	37.44	1.24	33.49	0.49
3m	III	36.93	0.40	32.85	0.42	29.64	0.49	23.71	0.20
		41.81	0.88	36.74	1.15	41.26	1.26	30.50	0.45
4m	III	30.40	0.47	41.44	0.37	23.81	0.53	28.95	0.19
		48.00	0.89	47.05	0.58	32.16	0.93	32.45	0.37
5m	III	26.06	0.36	36.06	0.21	34.07	0.32	31.37	0.27
		31.26	0.88	39.85	0.36	47.55	0.78	39.87	0.37

INFLUENCE BY VEHICLE CLASS

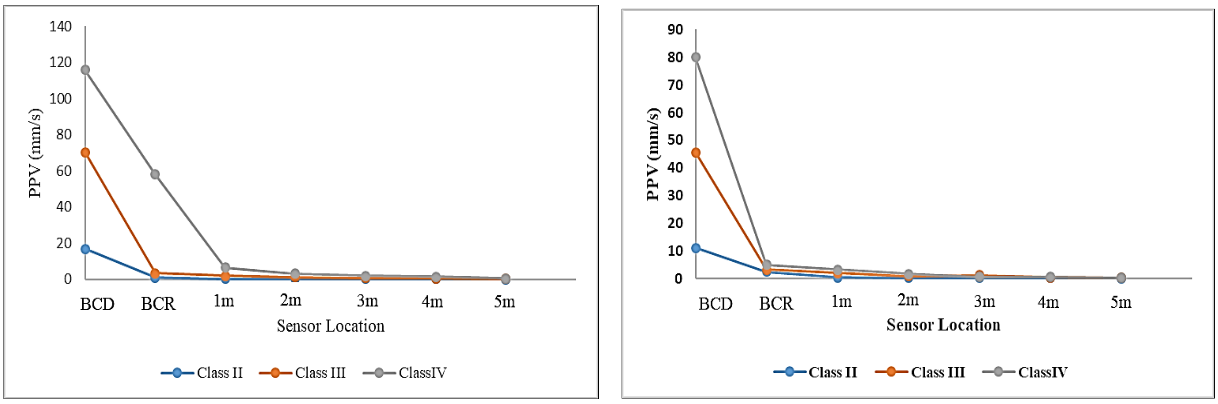
Table 4 shows data obtained more focused on vehicle class against PPV values at each sensor location and zone of vehicle at BAA and BAB.

Table 4: PPV value by vehicle class

Sensor Location	Vehicle Class	BAA Zone 2 Speed (km/h)	PPV (mm/s)	Zone 3 Speed (km/h)	PPV (mm/s)	BAB Zone 2 Speed (km/h)	PPV (mm/s)	Zone 3 Speed (km/h)	PPV (mm/s)
BC[D]	II	38.32	16.85	38.63	11.13	42.14	0.24	39.52	0.23
	III	37.61	70.41	39.71	45.60	34.94	1.82	37.21	0.80
	IV	27.15	115.92	48.95	80.06	36.97	3.86	41.26	1.59
BC[R]	II	32.11	1.01	43.86	2.48	32.16	0.20	58.50	0.19
	III	33.54	3.28	38.74	3.33	47.42	1.16	34.27	0.76
	IV	30.79	58.00	45.99	5.03	25.96	1.73	28.87	1.21
1m	II	37.03	0.32	47.52	0.38	39.52	0.22	28.45	0.16
	III	39.27	2.01	47.36	2.06	51.70	1.16	32.00	0.52
	IV	30.40	6.52	41.07	3.21	34.64	1.53	31.15	1.09
2m	II	44.27	0.34	46.59	0.30	52.15	0.19	42.75	0.15
	III	35.64	1.12	42.94	0.86	37.44	1.24	33.49	0.49
	IV	36.74	3.06	39.38	1.68	38.28	1.47	25.52	0.73
3m	II	38.63	0.22	55.04	0.27	52.62	0.19	49.96	0.12
	III	38.95	0.65	32.85	1.15	41.26	1.26	30.50	0.45
	IV	33.23	1.85	46.59	0.63	37.92	1.85	46.80	0.76
4m	II	40.39	0.18	56.35	0.24	35.57	0.15	30.72	0.13
	III	30.40	0.47	41.44	0.37	32.16	0.93	32.45	0.37
	IV	41.81	1.36	47.05	0.58	30.30	1.49	25.89	0.60
5m	II	50.55	0.12	48.99	0.18	35.78	0.13	48.20	0.12
	III	26.06	0.36	32.35	0.21	47.55	0.78	39.87	0.37
	IV	34.86	0.60	52.41	0.35	39.26	0.94	29.79	0.84

Figure 7 (a) and (b) shows the value of PPV based on the sensor location and vehicle class that via zone 2 and zone 3 at BAA. It shows a significant difference between the value of PPV at sensor location BC [D], BC [R] and 1m. Then, the value of PPV at sensor location 2m, 3m, 4m and 5m decreases with uniform rates. In this regard, it can be expressed here that the critical area is in the 1m area before a bridge connection.

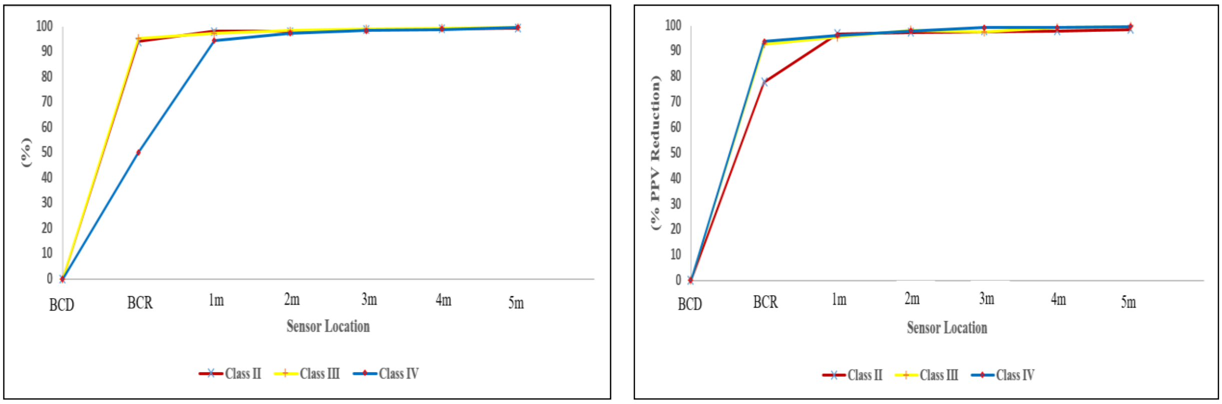
Figure 7: PPV value by vehicle class and sensor location in BAA



(a) Zone 2 (b) Zone 3

Figure 8 (a) and (b) shows, the percentage of PPV value changes (reduction) where the sensor location BC [D] is a reference point. From the observation of the data obtained at zone 2, it was found that the percentage between sensor location BC [D] and BC [R] for vehicle class II (94.01%), class III (95.34%) and class IV (49.97%) and at zone 3, for vehicle class II (77.72%), class III (92.70%) and class IV (93.72%). Meanwhile, the percentage between sensor location BC[D] and 1m at zone 2 for vehicle class II (98.10%), class III (97.15%) and class IV (94.38%). At zone 3, for vehicle class II (96.59%), class III (95.48%) and class IV (95.99%).

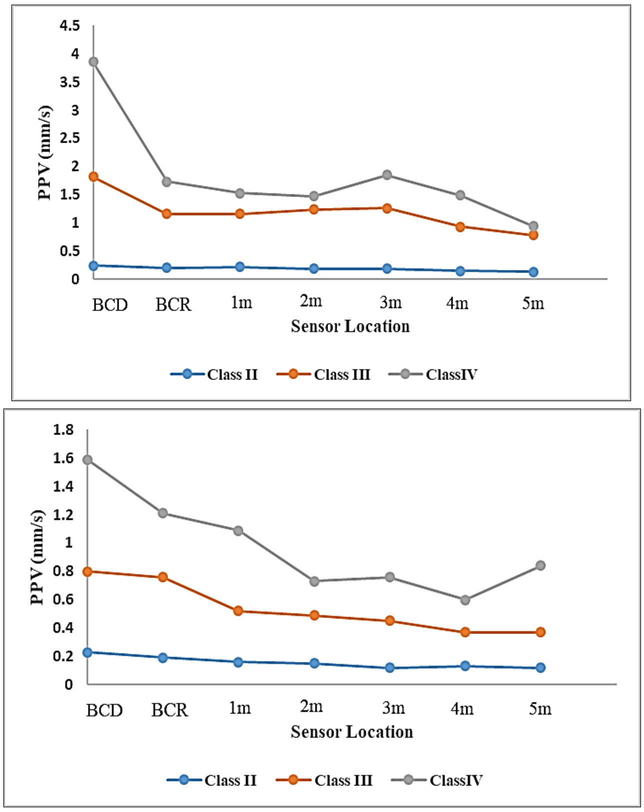
Figure 8: Percentage of PPV reduction by sensor location in BAA



(a) Zone 2 (b) Zone 3

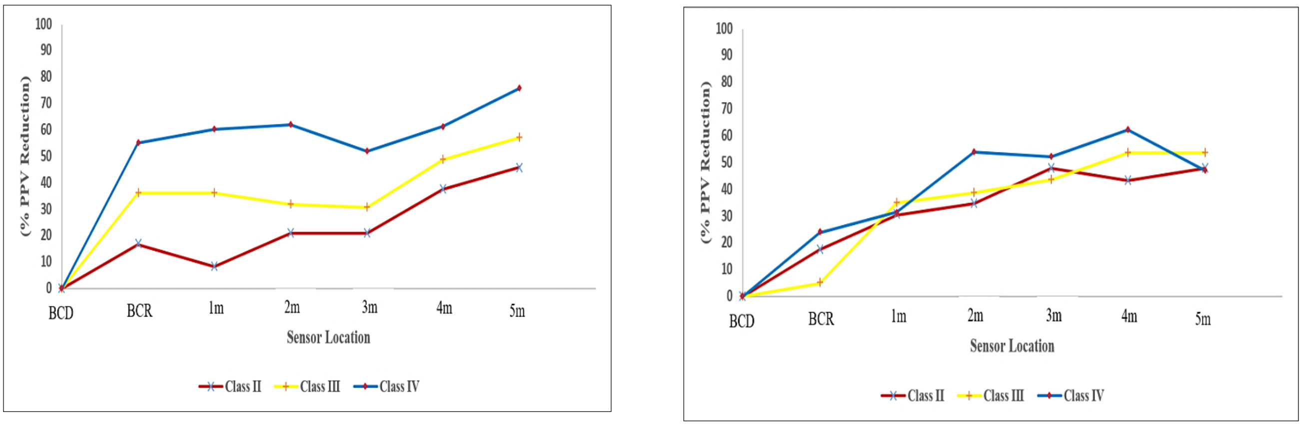
Furthermore, from data obtained at BAB explained by Figure 9 shows the value of PPV based on the sensor location and vehicle class that via zone 2 and zone 3. It shows a significant difference between the value of PPV at sensor location BC [D], BC [R] and 1m. Then, the value of PPV at sensor location 2m, 3m, 4m and 5m decreases with uniform rates. In this regard, it can be expressed here that the critical area is in the 1m area after a bridge connection.

Figure 9: PPV value by vehicle class and sensor location in BAB



(a) Zone 2 (b) Zone 3

Figure 10: Percentage of PPV reduction by sensor location in BAB



(a) Zone2 (b) Zone 3

Figure 10 shows, the percentage of PPV reduction value where the sensor location BC [D] is a reference point. At zone 2, the percentage between sensor location BC [D] and BC [R] for vehicle class II (16.67%), class III (36.26%) and class IV (55.18%) and at zone 3, for vehicle class II (17.39%), class III (5.00%) and class IV (23.90%). The percentage between sensor location BC [D] and 1m at zone 2 for vehicle class II (8.33%), class III (36.26%) and class IV (60.36%) and then, at zone 3, for vehicle class II (30.43%), class III (35.00%) and class IV (31.45%). The conclusion of this analysis of influence of vehicle class, the PPV value of BAA is higher than BAB.

INFLUENCE BY ZONE

Table 6 shows the data values obtained for vehicle class II and class III in BAA and BAB. Through the observation of this data, it is found that zones also play an important role in demonstrating the value of PPV. It is found that the value of PPV decreases when the vehicle passes through zone 3 versus zone 2 on both classes of vehicles against the location of the sensor being observed. With this, it can give an impression that when the vehicle shuts off the sensor, the value of PPV indirectly also shows a reduction.

Table 6: PPV value by zone of vehicle

Sensor Location	Vehicle Class	Zone	BAA Speed (km/h)	PPV (mm/s)	BAB Speed (km/h)	PPV (mm/s)
BC[D]	II	2	38.32	16.85	42.14	0.24
		3	38.63	11.13	39.52	0.23
	III	2	55.04	68.40	34.94	1.82
		3	42.97	45.60	37.21	0.80
BC[R]	II	2	32.11	1.01	32.16	0.20
		3	47.05	0.54	58.50	0.19
	III	2	33.54	3.28	47.42	1.16
		3	38.74	3.33	34.27	0.76
1m	II	2	37.03	0.32	39.52	0.22
		3	46.59	0.27	28.45	0.16
	III	2	53.59	2.28	51.70	1.16
		3	47.36	2.06	32.00	0.52
2m	II	2	44.27	0.34	52.15	0.19
		3	46.59	0.30	42.75	0.15
	III	2	35.64	1.12	37.44	1.24
		3	42.94	0.86	33.49	0.49
3m	II	2	38.63	0.22	52.62	0.19
		3	55.04	0.27	49.96	0.12
	III	2	38.95	0.65	41.26	1.26
		3	36.74	0.42	30.50	0.45
4m	II	2	40.39	0.18	35.57	0.15
		3	47.05	0.19	30.72	0.13
	III	2	30.40	0.47	32.16	0.93
		3	41.44	0.37	32.45	0.37
5m	II	2	50.55	0.12	35.78	0.13
		3	48.99	0.18	48.20	0.12
	III	2	26.06	0.36	47.55	0.78
		3	32.35	0.21	39.87	0.37

CONCLUSION

Ground vibration measurement need to be conducted in correct procedures using the proper equipment. Knowledge and experience is needed when conducting ground vibration measurement to avoid inaccurate data due to various causes for examples from device preparation, transducers mounting, equipment handling, acquisition software parameter setting, and recognition of the displaying vibration data. At the same time, a necessary skill needed when handling this sensitive equipment to protect from damage and loss of signal. From the analysis carried out through the measurement of the vibration value at the site location, found that the three variables play their respective roles. By comparison of the variables that had been conducted with respect to the value of this vibration, it was found that the zone near the sensor shows a higher PPV value compared to the zone that is far apart from the sensor. Other than that, when the speed of the vehicle increases indirectly the PPV value also increases and vehicle class also plays a role which class IV is higher than class III and class II. Constraints during testing are related to the installation of equipment, which must be done carefully to avoid unwanted events. The time for a single test is very limited because it depends on the laptop's battery capacity of around 2 hours and requires additional power in the future to extend the duration of the observation. The advantages of this study to provide and improve the knowledge towards the importance of the vehicle loading of specific evaluation As a result of this study, it will serve as a reference for the next study in which the factors of the vehicle causing vibration to the bridge approach must be taken into account by the authorities in designing a future project.

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