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Condition monitoring of overhead line equipment (OHLE) structures using ground-bourne vibrations from train passages

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ABSTRACT: The most modern railway systems have fully adopted clean energy for train and track operations. Trains or rolling stocks are powered by electricity through the overhead wire or the third rail on ground. Commonly, the overhead line equipment (OHLE), which supplies electric power to the trains, is widely adopted in new railway networks around the world since its system enables trains to operate smoothly while track inspectors can safely work on tracks. The OHLE is supported by mast structure, which is located at the lineside along the track. The mast structure is often made of steel structure built on mat or pile foundation. Due to the train passages, ground-bourne periodic forces may cause damage to the OHLE structure especially mast structure, connections and its foundation, which can lead to operational failure of train electrification. On this ground, the structural integrity of mast structures must be inspected regularly. In this study, the modal analysis is used in order to identify the mode shapes and natural frequencies of the mast structure. A mast structure with varying rotational soil stiffness is used to construct dynamic influential lines for soil-structure integrity prediction. Finite element model updating technique has been used to perform modal analysis and modal parameter identification. This paper presents the integrated numerical of three-dimensional mast structure considering soil-structure interaction to evaluate the condition of OHLE structures for maintenance planning. The outcome of this study will help civil and track engineers to effectively and efficiently inspect OHLE structures using ground borne vibrations from train passages.

INTRODUCTION

Nowadays, the extra capacity of passenger train is needed due to the sudden growth of population and journeys (RailCorp, 2011). It was noticed that freight and passenger journeys have increased by 60% and 100%, respectively. To get the destination faster, electric train has become the efficient railway systems, which are allowed to run more frequent and quicker than conventional diesel train. Also, electric train is more environmental friendly as it emits less carbon than diesel counterpart. Instead of carrying the fuel to make the train runs, the power is supplied by the Overhead Line Equipment (OHLE), which consists of masts, gantries, wires found along electrified railways. The electric system can be failed and the power supply can be lost. As seen in literature (Shing and Wong, 2008; Robinson and Bryan, 2009; Taylor, 2013), extreme environmental events such as snow storm, strong wind, earthquake etc., have affected railway track and OHLE, especially single mast structure (FIG. 1), which is very slender and flexible (Beagles et al., 2016). Hence, condition monitoring of railway track and its overhead line components is needed for maintenance planning (Ngamkhanong et al., 2018). Besides, ground bourne vibration from train passage is also one of the serious concern as it affects property and cause annoyance to people in surrounding area (Suhairy, 2000; Lopes et al., 2016; Connolly et al., 2016).

Based on previous studies (Kouroussis et al., 2013; Zou et al., 2015; Mouzakis and Vogiatzis, 2016; Zou et al., 2017; Vogiatzis and Mouzakis, 2017), it can be seen that the effect of ground-bourne vibrations from train passages on building have been established. However, the responses of mast structures, which are located closer and along the railway track, have not been fully studied. Modal analysis has been used to study vibration mode of cantilever mast structure. Crossing phenomena was observed when support stiffness reduced as this structure has a sensitivity under vibrations (Ngamkhanong et al., 2017). It was confirmed by previous studies that soil-structure interaction affected the overall response of the structure (Prum and Jiravacharadet, 2012; NEHRP, 2012).

Due to the increase of train speed, ground-bourne periodic forces may cause damage to the OHLE structure especially mast structure, connections and its foundation, which can lead to operational failure of train electrification. This study aims to present the integrated numerical study of three-dimensional cantilever mast structure considering soil-structure interaction to evaluate the condition of OHLE structures for maintenance planning. To monitor the OHLE condition, adaptation technique is used by monitoring the condition of single mast structure, which its response affects the overhead wire movement. At this stage, the movements of overhead contact wire are measured based on finite element modelling. It is noted that only finite element modelling is employedusing finite element package STRAND7 (G+D Computing, 2001). Ground borne vibrations are computed by the classical formulation based on the semi-empirical model for predicting low frequency vibration on soft ground condition (Kurzeil, 1979; Madshus et al., 1996). The frequencies of ground borne vibration between 0Hz and 100Hz are considered to cover all possible frequencies of ground vibration and the first-eight fundamental mode of mast vibration (Kouroussis et al., 2014; Kouroussis et al., 2015; Ngamkhanong et al., 2018). This study presents the maintenance index which can be used for maintenance planning and inspection of support condition of mast and OHLE structures. Moreover, it should be noted that on-site measurement will be further conducted in the next step. The outcome of this study will help civil and track engineers to effectively and efficiently inspect OHLE structures using ground borne vibrations from train passages.

METHODOLOGY

Modelling

In this study, it is assumed that mast structure is placed 3.5m far from railway track in perpendicular. Three-dimensional modelling of single mast structure is constructed using finite element package STRAND7 (G+D Computing, 2001). The parametric study of the soil stiffness and train speed is conducted. It is assumed that translational stiffness (k_x, k_y) of support is fixed in all directions, while the rotational stiffness (k_{zz}) is varied from 1000 to 1000000 kNm/rad (fully fixed support condition). It is noted that the rotational stiffness is affected by the soil-structure interaction condition and the quality of support connection. The support stiffness can be decrease due to the connection failure such as broken bolt, yielding weld, improper design and construction etc. and soil erosion and degradation. The 2-D schematic load to structure with support stiffness is shown in FIG 2. The typical H-section steel (Section area: $2.219\text{x}10^{-2}$ m^2, I_{zz}: $5.08\text{x}10^{-4}$ m^4, I_{xx}: $1.84\text{x}10^{-4}$ m^4) is used and connected to the cantilever which made of round steel to support the overhead contact wire. It should be noted that the interesting point is at the end of cantilever which is the location overhead contact wire. The steel used has the young modulus of $2\text{x}10^5$ MPa, density of 7850 kg/m^3 and poisson's ratio of 0.25.

Condition Monitoring

In general, the overhead contact wire forms in a zig-zag path (also called "stagger") above the track to avoid wearing a groove in the pantograph. Thus, the overhead wire displacement in transverse direction affects overhead line system which has limitation of sway movement. The allowable displacement is assumed as construction tolerances of contact wire. Hence, 50mm construction tolerance of contact wire is used as the maximum displacement at the end of cantilever mast in transverse direction (RailCorp, 2011). This study presents the adaptation technique for overhead line equipment monitoring. As the movement of mast structure can affect the movement of contact wire, the sensors should be placed in several positions in order to monitor the responses of mast structure affected by passing train and other environment impacts. However, this study only demonstrates the finite element modelling instead of on site monitoring. It is recommended to monitor the OHLE condition on real site to compare with numerical results.

Ground Borne Vibration

It was noted that the fundamental modes of vibration of mast structure can be changed due to the reduction of support stiffness (Ngamkhanong et al., 2017). Crossing phenomena was observed at the low frequency when the support stiffness was reduced. Hence, to cover all the fundamental modes of vibration, the frequency range between 1 and 100 Hz is considered. The train speed varies from 100km/h to 300 km/h. When the train passes the mast structure, ground bourne vibrations are generated in both directions (longitudinal and transverse). The vibration velocities on the ground are based on several factors such as ground condition, train type and speed, distance from track to structure etc. The ground bourne velocity can be calculated using the formula by Madshus et al. (1996) as seen in Eq. 1

$$V=V_T F_S F_D F_R F_B \tag{1}$$

Where V_T is a train type specific vibration level, F_S is a speed factor, F_D is a distance factor, F_R is a track quality factor and F_B is a building amplification factor.

The vibration parameters are calculated based on the literature (Madshus et al. (1996)). The train type specific vibration level, (V_T) of 0.1 is used since it is assumed that the trains run along the track on soft ground. The speed factor (F_S) is calculated from the ratio between train speed (S) and the reference speed on standard track (S_0 =70 km/h). The distance factor (F_D) can be calculated from the ratio between the centre of the track to the receiver and the reference distance from the centre of the tracks (20 m). It is assumed that the railway line considered is a single track and is assumed to be the same type of single story building based on the height of mast structure. Thus, the track quality factor (F_R) and building amplification factor (F_B) are 1.3 and 1.3.

This study considers the velocities generated by train at the different locations of running train on track. The ground vibration velocities are applied as harmonic excitations in both longitudinal and transverse directions. The vibration creation regions are formed on the track at the different angles which make the different vibration velocities. It is noted that the critical angle is 90 degrees since this can generate the highest vibration velocities in transverse direction, as shown in FIG. 3.

RESULTS AND DISCUSSIONS

Maximum Displacement

The maximum displacements at the end of the cantilever, which is the location of overhead wire, in both directions are presented, as shown in FIG. 4. It should be noted that the direction concern is transverse as this is a sway direction of overhead wire.

At fully fixed support condition (FIG. 4a), it is clearly seen that the train speed plays a little role on transverse direction when angles of the train to the mast are in low range (less than 30 degrees) but plays a significant role at higher angles. For 70-90 degrees, it should be noted that the maximum displacement in transverse direction increases nearly double and triple from the speed of 100km/h to 200km/h and 300km/h, respectively. This can also be observed in case of lower support stiffness (FIG. 4b).

It is clear that the transverse displacement is higher than longitudinal. About 42mm is observed as a highest transverse displacement.

Maintenance Index

The ratio between the overhead contact wire displacement and allowable displacement (50 mm) is indicated as maintenance index. It is assumed and noted that the allowable displacement used is the construction tolerances of contact stagger according to RailCorp (2011). As seen from FIG. 5, it is shown that mast structure with support stiffness of 1000 kNm/rad under the ground bourne vibration generated by 300 km/h train speed has the highest maintenance index (0.83). Even thought, all cases are under maintenance level, with support stiffness of 1000kNm/rad, the maintenance index tends to reach the maintenance level. Thus, by linear extrapolation, the contact wire on single mast with support stiffness of 1000 kNm//rad needs to be under maintenance as the maintenance index equal to 1 at the train speed of 361 km/h.

CONCLUSIONS

The overhead line equipment (OHLE), which supplies the electric power to the train, is one of the most vulnerable asset of the railway infrastructure. The electric system can be failed due to the large movement of overhead wire under harsh environment. The end of cantilever is a position concern as it holds the overhead contact wire. This study considers the variation of support stiffness of mast structure and vehicle speed from 100 to 300 km/h. It should be noted that support stiffness can be reduced by many reasons such as broken bolt, yielding weld, soil erosion and degradation. Thus the soil-structure connection should be carefully constructed. It is interesting that OHLE can be reached the maintenance level under the train speed of about 360km/h in case of mast placed on poor support. The obtained results can be also used to detect the support condition and maintenance index for OHLE on real track site. The outcome of this study will help a better understanding of the critical responses and dynamic behaviour of cantilever mast structure and its support subjected to ground bourn vibrations in order to improve the further design standard of this structure. The finding of this study can also help improve inspection of OHLE structure. However, this is the first to study and monitor the condition of OHLE structure subjected to ground bourne vibrations from train passages, the onsite monitoring and measurement will be further conducted in order to verify the obtained results..

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FIGURES

FIG. 1. Cantilever mast structure

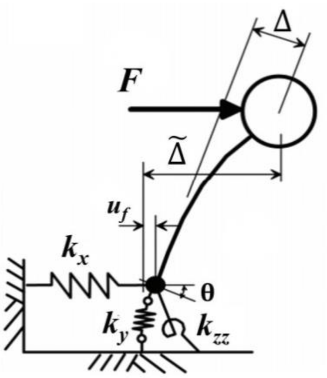


FIG. 2. Schematic load to structure with support stiffness

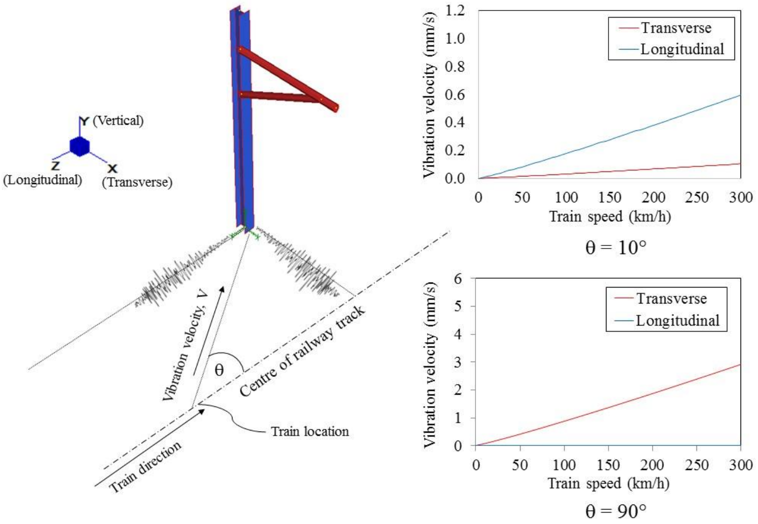
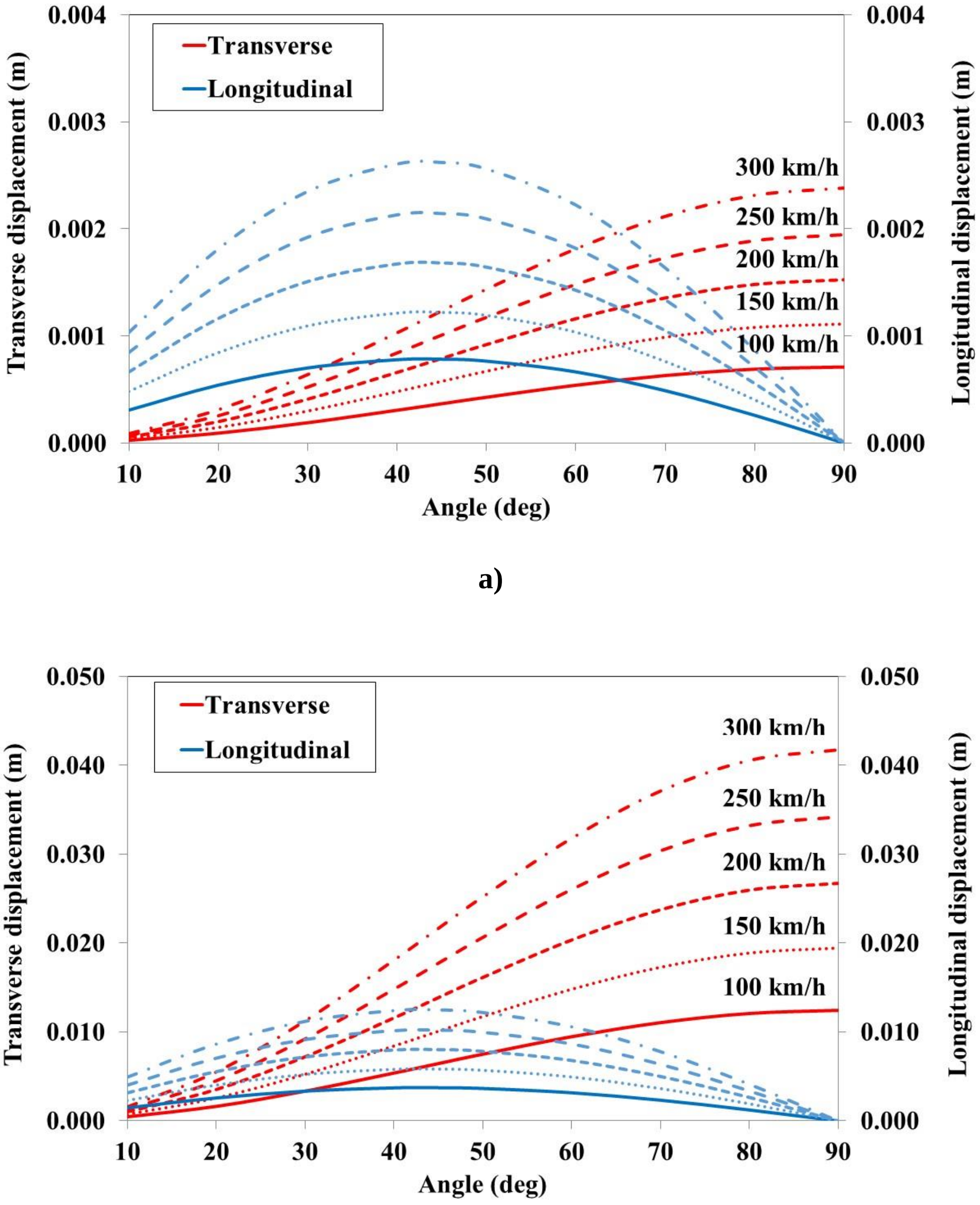


FIG. 3. Single mast structure modelling and ground vibration velocities from train passages



a)

b)

FIG. 4. Maximum displacements at the position of overhead contact wire on cantilever mast with support stiffness of a) 1000000 kNm/rad (Fully fixed) b) 1000 kNm/rad

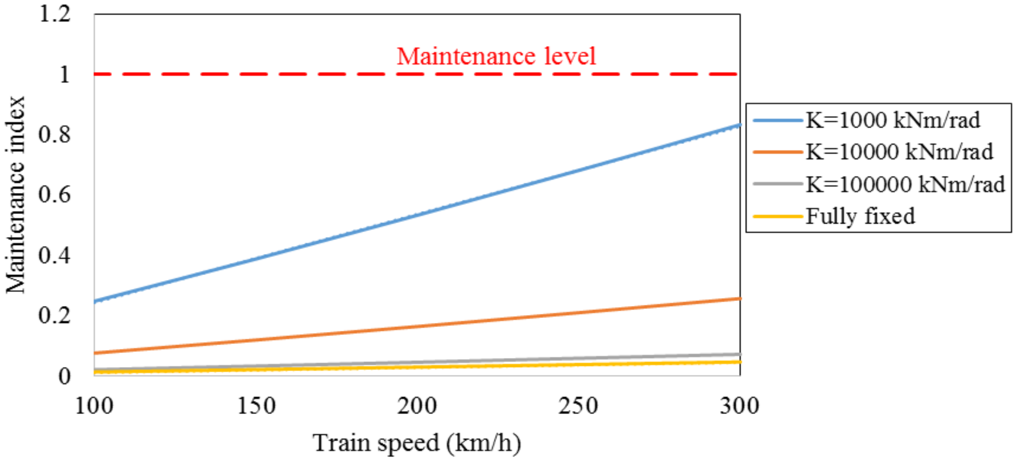


FIG. 5. Maintenance index