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EFFECT OF SPEED & WEIGHT TRAIN ON THE SURROUNDING VIBRATION TUNNEL ON THE GROUND SURFACE

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Abstract

Development of technology has made it possible to excavate underground spaces in different geological conditions. With respect to the increase of usage and importance of tunnels in transportation systems in urban areas, it is necessary to investigate the response of dynamic loads due to train movements. To receive this purpose, one series of studies has been done on subway system in Tehran that named LINE4. Because these tunnels were excavated in soil, the model was considered as a continuum conditions, thus the commercial program FLAC3D is used.In this research, the effect of speed and weight train is studied on the surrounding vibration tunnel on the ground surface. To investigate the effect of train motions, speed and weight trains are assumed as the effective factors to calculate the vertical applied load transferred from wagons to the rails in terms of time in a longitudinal model. The analysis of train movements showed that particles velocity level in two directions (vertical and horizontal) increases with increase the train speed and weight. Also, the maximum velocity of particles is smaller than damage. Therefore, there is no concern about structure damages, but it can still cause people inconvenience. Also, effect of train weight in particles velocity level is more than of train speed.Andfinally,the result shows that, to reduce the vibration level, it is better to use light wagons in transportation systems..

Introduction

Underground structures are an integral part of the infrastructure of modern society that has broad applications such as subways, tunnels, railroads, highways, energy storage and etc. Due to the increasing development of tunnels and their importance in the transport network between intra-urban and urban areas is essential to examine the tunnel dynamic response against dynamic loads in normal and abnormal types.

For the first time train-induced ground vibrations were evaluated byKennedyandHerman in 1973. He presented an analytical model of a viscoelastic medium, to examine rate of earth vibration against moving point load [1].

Train-induced ground vibrations in the underground tunnels are important and in recent years are widely considered. Frequency vibration caused by trains are changing in the range 2-200 Hz, therefore, the vibrations could cause significant environmental impacts. Excessive ground vibrations may have a significant impact on human comfort and on the built environment. A vibration is annoying to humans if the peak ground velocity (PGV) exceeds 2.5 mm/s, while a typical value for the onset of structural damage is 50 mm/s. Significantly lower values apply for ancient buildings or monuments [2], [3].

In Czechoslovakia, some ancient buildings of masonry construction close to busy roadways and railways have cracked due to the vibrations induced by passing vehicles (Fig. 1). With the growth of the cracks, some old churches and houses have been damaged or have even collapsed in Prague,Hustopece and Hrusov areas [4].

To evaluate the speed and weight of trains by software FLAC3D is used characteristics of wagon, rail and data of subway system in Tehran that named LINE4. The purpose of analysis tunnel against train loading is investigated the effect of train moving on the surrounding vibration tunnel

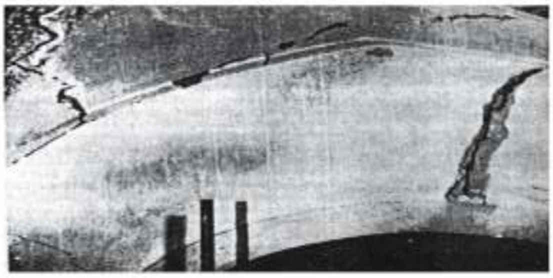

Fig. 1. Vibration caused crack of an old church near road [4].

Numerical modeling

To receive this purpose, one series of studies has been done on subway system in Tehran that named LINE4.Metro Line 4 project in the direction east-west of Tehran, connects Tehran Pars to Ekbatan in west of Tehran that used New Austrian Tunnelling method (NATM) for tunnel excavation.

Cross section of Metro Line 4 is shown in Figure 2.According to data from boreholes in Line 4, the results of geotechnical data is shown in Table 1.

A study done in the area shows groundwater level is relatively deep that there is no problem in view of it.According to the information and models of software, Mohr-Coulomb behavior model selected as a good behavior model.

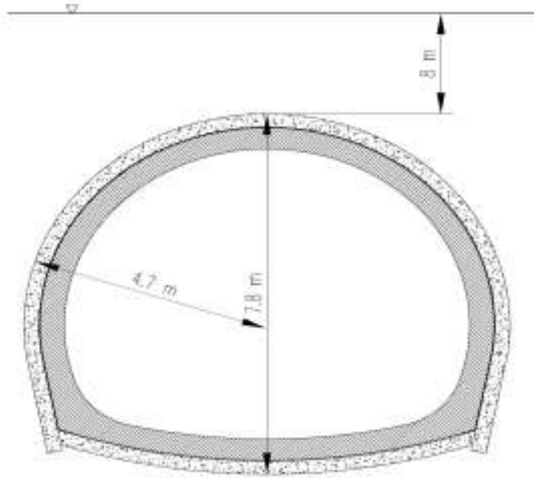

Fig. 2.Tunnelgeometryand it position in depth.

Table 1.Geotechnicalproperties ofthe Tehran MetroLine 4 [5].

	γ gr/cm^3	C Kpa	φ °	E Mpa	υ
Isoil	1.9	29.43	35	80	0.27
IIsoil	1.9	19.62	38	100	0.27
IIIsoil	1.9	24.52	36	90	0.27

Three-dimensional view of the model to investigate the effects of speed and weight train is shown in Figure 3.

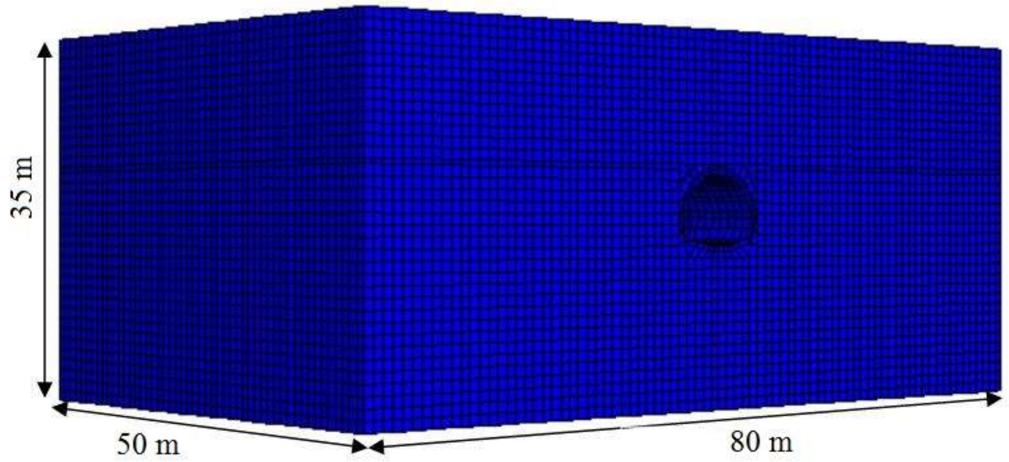

Fig*. 3.Three-dimensional view of the model to investigate the effects of speed and weight train.*

In this study is used Rayleigh damping components proportional to mass and critical damping ratio $\left(\xi_{\min}\right)$ of 2% for numerical analysis.Natural frequency created model is 1.75Hz.In order to prevent the reflection of waves into the model is used viscous boundaries.The different relationship presented in this regard,that FLAC3D program is used viscous boundaries proposed by Laysmr and Kalmyr [6].

Train loading

A study dynamic response of ground against force of train moving investigated into the various branches of engineering.In recent years with introduction of high-speed passenger trains and heavier freight trains to rail transport system, the importance of dynamic response of ground against dynamic loads due to train moving is higher [7], [8].

Vibrations produced because of large forces between wheel and rail. These forces produced in effect roughness between wheel and rail which have a wide frequency range. It should be noted that even for train wheels on rails perfectly smooth, regular vibrations caused by load of train moving. The hybrid system of vehicle and rail is very complex and has many natural frequencies. When the natural frequency of vibration sources is equal to the natural frequency of system, vibrations will occur with considerable power. With increasing speed and matching frequencies, vibrations are close to its maximum value and then decreases abruptly [9], [10].

Railway vehicles are complex mechanical systems, have many degrees of freedom because of springs, linear and nonlinear damping. Train moving created three-dimensional forces at path railway. These forces are vertical forces (vertical wheel Load), longitudinal forces (braking force and the force at the beginning of motion) and transverse forces (centrifugal force and lateral impact) [2]. With considering all the above forces in modeling, the model complicated. In most engineering problems is used the simplified mode for modeling. Simplification of the model depends on the purpose of the analysis. For example, if the main objective is investigating the response of train-induced ground vibrations, applying contact details of wheels and rails, and similar factors that have only local effects, would be meaningless.

In reality, there are many other sources supplementing vibrations caused by track structure response. Some of those are summarized in Table 1. They can spread on the soil medium and path structure to reach the nearby buildings. Ground vibrations transfer process induced by train is shown in Figure 9 [9], [10].

In discussion of train-induced vibrations can be identified four main phases:

1. Production: vibrations caused by the train loading on the rails.
2. Transmission: wave propagation between surroundings.
3. Receive: vibrations are absorbed by nearby buildings.
4. Prevention: vibration reduction with implement of barriers wave like trenches, isolation pads and etc.

Table 2.Different factors influencing the level and characteristics of train-induced ground vibrations [10].

Stress waves induced by the track structure response • Axle weight • Spacing of wheel axles • Speed of train
Vibration source at wheel-rail interface • Dynamic properties of the vehicle bogie • Wheels defects (eccentricity, imbalance, flats) • Misalignment of motors • Acceleration and deceleration of train
Discontinuity on the track • Rail defects (unevenness, waviness) • Spacing and interval of rail joints • Switches • Curves and tilting track (centrifugal forces)
Variable support • Geometry, stiffness and spacing of sleepers • Geometry, stiffness and heterogeneity of the ballast • Stiffness and geometry of the ground

In each phase, various factors are effective.Track structural response against train moving depends on speed, weight of train and distance between wheels axle.These parameters are the most effective parameterbut in addition, other factors such as type of train, track design, ground conditions, type and foundations of buildings and distance between rails and buildings are effective on train-induced ground vibrations [9], [10].

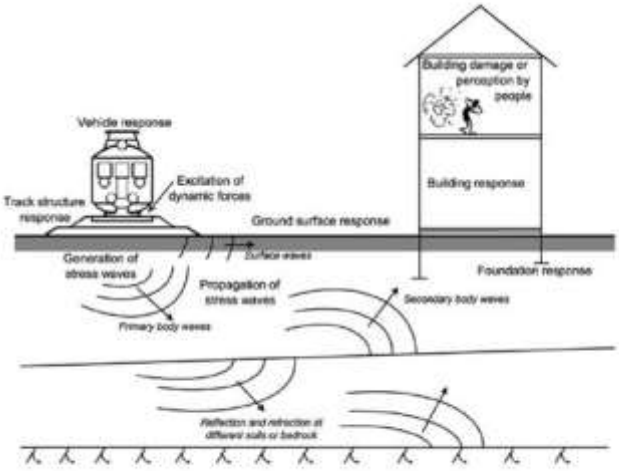

Fig. 4.The transmission process of train-induced ground vibrations [10].

Prediction of train-induced ground vibrations has three major problems:

1. The complexity of the dynamic interaction between the train-track-soil.
2. High natural frequency ground moving, that use of 3D models remains as a challenge.
3. Lack of good experimental data for calibration of numerical calculations.

In this study, to overcome these problems, train considered separately from rail-soil system, the effect of it modeled by using a series of static forces moving with constant speed on rail that interaction train-track are not considered.Exerted force from train to floor is calculated as models length of the wagons that this force is applied to the floor of the tunnel in numerical model as distributed load along the rail.

Concerning the train-induced vibrations on the soils, the loadings are transmitted to the track and underlying soils through the contact points existing between the wheels and rails. Depending on the nature of loadings, they can be spilt up into two parts as depicted in Fig. 5. The first part relates to the distribution of the axle loads passing a fixed point given as Ø(z-ct), where c is the speed of the moving loads and Ø(z) is the distribution function of each axle load [9].

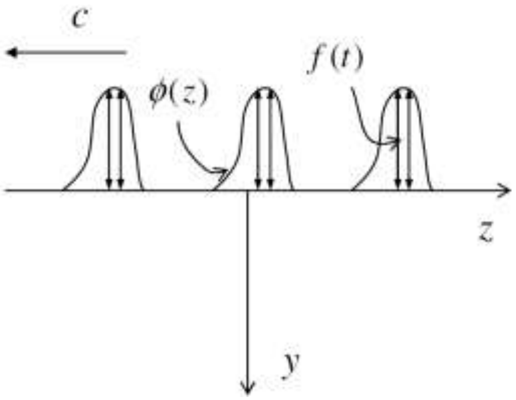

Fig. 5.Schematic diagram of a train-induced general moving load [9].

If the wheel load is regarded as force exerted from track onto underlying soils, rather than the one from the wheels onto the track, one may use the deflection curve of the track to simulate the distribution of the wheel load. In this connection, the track is treated as an infinite Bernoulli- Euler beam supported by an elastic foundation of stiffness s and EI denote the bending stiffness of the beam. For an elastically supported beam with an axle load T acting at z = 0, the vertical displacement v is:

$$v(z)=\frac{T}{2s\alpha}\exp\left(\left|\frac{-z}{\alpha}\right|\right)\left[\cos\left(\left|\frac{-z}{\alpha}\right|\right)+\sin\left(\left|\frac{-z}{\alpha}\right|\right)\right] \qquad (1)$$

Where the characteristic length α can be related to the bending stiffness EI as:

$$\alpha=\sqrt[4]{\frac{4EI}{s}}\ \ (m) \qquad (2)$$

With $s(N/m^2)$ denoting the spring coefficient of the foundation.
Consequently, the load distribution function can be written as

$$\varnothing(z)=q_0(z)=\frac{T}{2\alpha}\exp\left(\left|\frac{-z}{\alpha}\right|\right)\left[\cos\left(\left|\frac{-z}{\alpha}\right|\right)+\sin\left(\left|\frac{-z}{\alpha}\right|\right)\right] \qquad (3)$$

Let us extend the single wheel load case to the case of a train consisting of N carriages of equal length L in Fig. 6. Here, each carriage is assumed to have two bogies separated by distance *b*, each of which in turn comprises two axles, i.e., two sets of wheels, separated by distance *a*. Suppose that each set of wheels has the same load distribution function $q_0(z)$ as the one given in Eq. (3). The total distribution function of loading for the present case can be written as:

$$\varnothing(z)=\sum_{n=0}^{N-1}\begin{bmatrix} q_0(z-nL) \\ +q_0(z-nL-a) \\ +q_0(z-nL-a-b) \\ +q_0(z-nL-2a-b) \end{bmatrix} \qquad (4)$$

The second part produced by interaction between wheel and railthat shown with f(t) and independent on the direction of motion.In fact, the interaction force between wheel and rail can be simulated by a static term and dynamic part that varies with time.
The static term is contributed mainly by the wheel weight, whereas the dynamic term by the track irregularities and vehicle defects, such as wheel flats. The dynamic term is extremely complex and there is no exact analytical model [9]

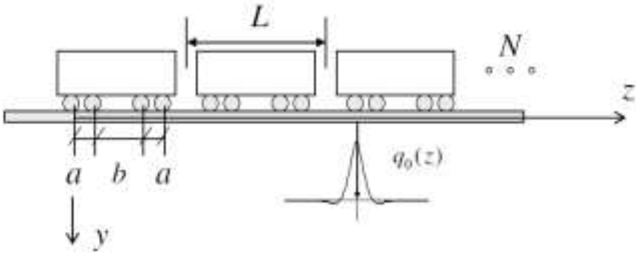

Fig. 6.Train-induced loadings between the rails and soil [9].

Characteristics of wagons and rail of Tehran Metro is used for modeling, in presented below [5]:
1. Length of wagons (L): 19.3 m
2. Distance between two bogies (b): 12 m
3. Distance between two wheels (a): 2.1 m
4. Number of wagons (N): 4
5. Bending stiffness (EI): 4.676 MN.m^2
6. Spring coefficient of the foundation (s): 100 MN/m^2
7. Characteristic length (α): 0.66
8. Maximum speed of operation:80 km/h

Train length is between 140 to 160 meters, be dependent on number of wagons,the investigation is shown that number of wagons for more than 4have less effect onto vibration velocity of particles.Therefore in this research used 4 wagons to reduce time solution of numerical modeling [9].

After determining the dynamic load of the train, the best way to evaluate the characteristics of dynamic loads transformed vibration motion from time domain to the frequency domain with using the Fourier transform.Although the Fourier amplitude spectra alone does not present a complete description of the dynamic load, but is a useful tool for determining the relative importance of different frequencies dynamic loads.In other words, since the major part of the energy dynamic load is related to frequency close to zero. According the Fourier amplitude spectra can be detect the frequency related to maximum wave energy and be overlooked of high frequencies.

Effect of speed train

Dynamic load of train has been modeled for speeds of 80, 100, 120 and 140 km/h and the wagons weight of 50 tons, using equation 4 and characteristics of Tehran Metro.Dynamic load of trains and the Fourier amplitude spectra for different speeds is shown respectively in figure 7 and 8.

According to studies done on the Ledsgard Sweden site, show the maximum measured wheel force changed less with increase train speedfrom 80 km/h to 120 km/h [11].Increasing train speed reduce period of dynamic load, in other words,frequencies of dynamic load increase so that power of vibration increased on the ground surface. In this study, with increasing speed, the force from each wheel is changed less and dynamic load frequency content is changed that shown in figure 7.Frequency range of dynamic load increased with increasing train speed (figure 8).

The modeling results show, with increasing train speed, vertical component of particle velocity increased in floor of the tunnel (Figure 9).

Also modeling results show thatin the general casewith increasing train speed, vertical component of particle velocity on the groundincreases, butthis increase do not show a clear trend with distance from axis of the tunnel (Figure 10).With changing frequency content, maximum particle velocity on the ground is different and with increasing frequency of load,vertical component of particle velocity on the groundhave maximum and minimum points more than lower speed.Different frequencies of wave, causes the particlevelocityatdifferent distancesismore orless than surrounding environment,generally can be concluded, with increasing distance and wave damping, level of particle velocity decreases.

Horizontal component ofparticle velocity increases with increasing train speed (Figure 11).

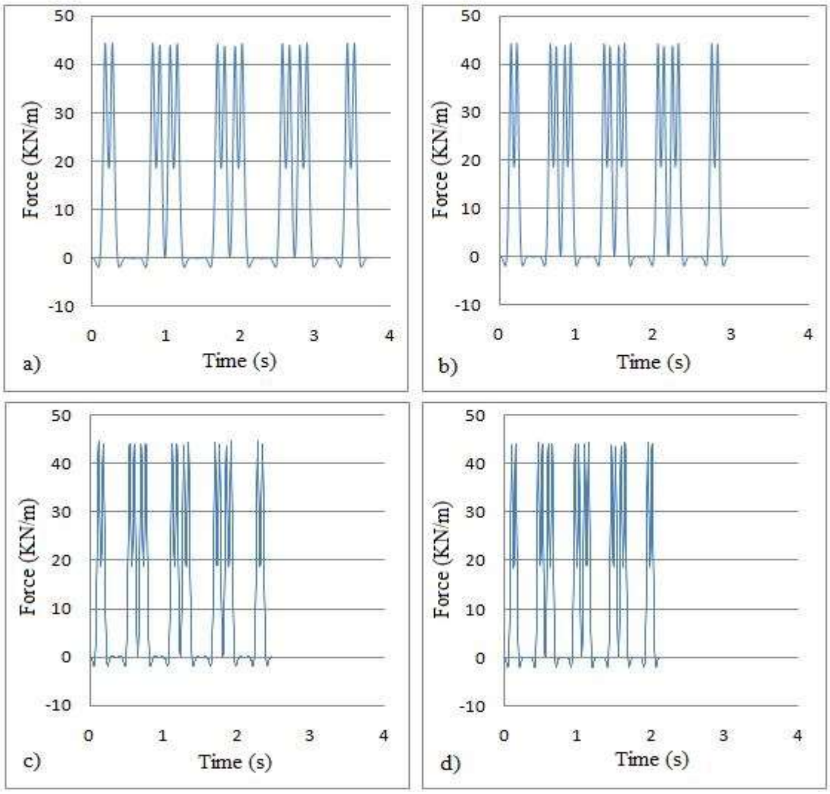

Fig 7.Dynamic load of train for speeds a) 80, b) 100, c) 120 and d) 140 Km/h.

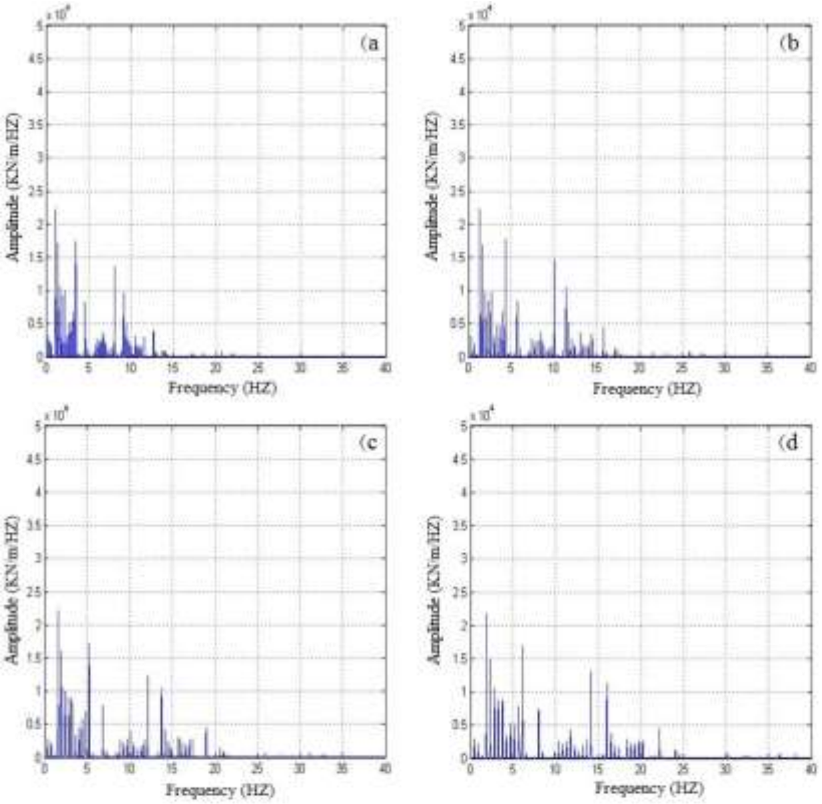

Fig 8.The Fourier amplitude spectra for speeds a) 80, b) 100, c) 120 and d) 140 Km/h.

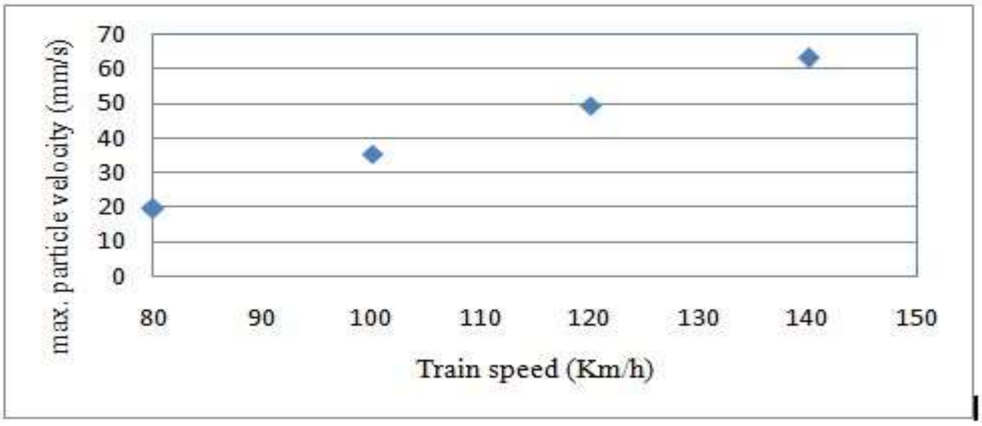

Fig. 9.The effect of train speed on vertical component of particle velocity in floor of the tunnel.

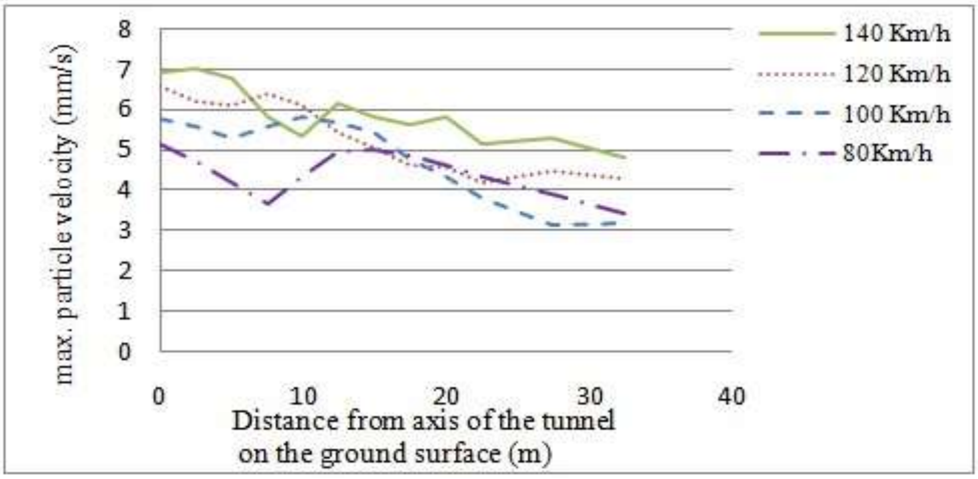

Fig. 10.The effect of train speed on vertical component of particle velocity on the ground surface.

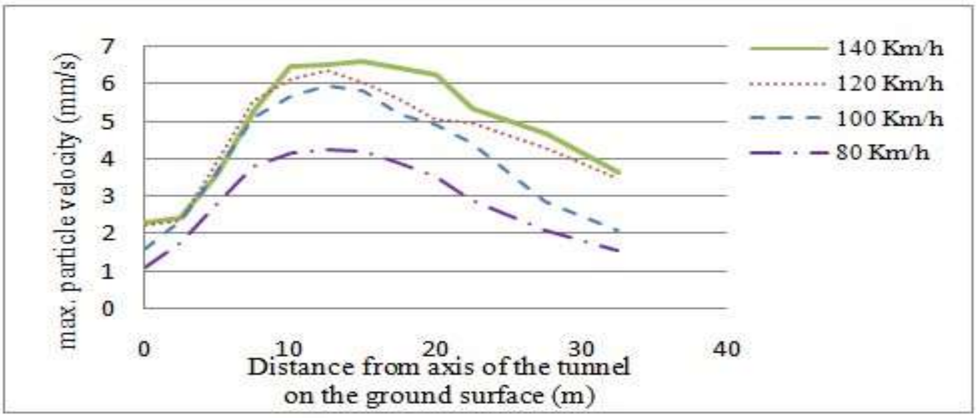

Fig. 11.The effect of train speed on horizontal component of particle velocity on the ground surface.

Effect of weight train

The wheel force is an important factor in the particle velocity. Dynamic load of train is modeled for three wheel force 62.5, 125, 175 KN (wagons weight 50, 100, 140 ton) with speed 80 Km/h. Also forbetter illustrate theeffect offorcewheelsusedtwotrain for modeling.

The modeling results show that with increase in wheel force, the particle velocity increases in floor of the tunnel and risk of damage to the tunnel lining increases (Figure 13).

Level of particle velocity increase in two directions (vertical and horizontal) with increases axial force (Figure 14 and 15).Comparing figures 14 and 15 show that the particle velocity in vertical direction is more than in horizontal.

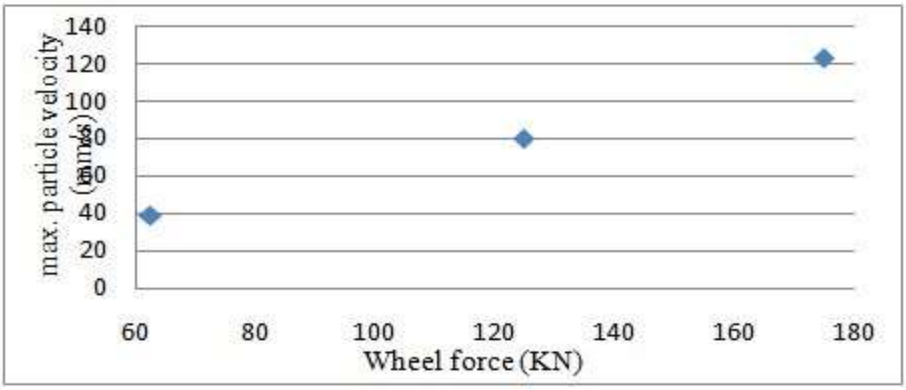

Fig. 13.The effect of wheel force on vertical component of particle velocity in floor of the tunnel.

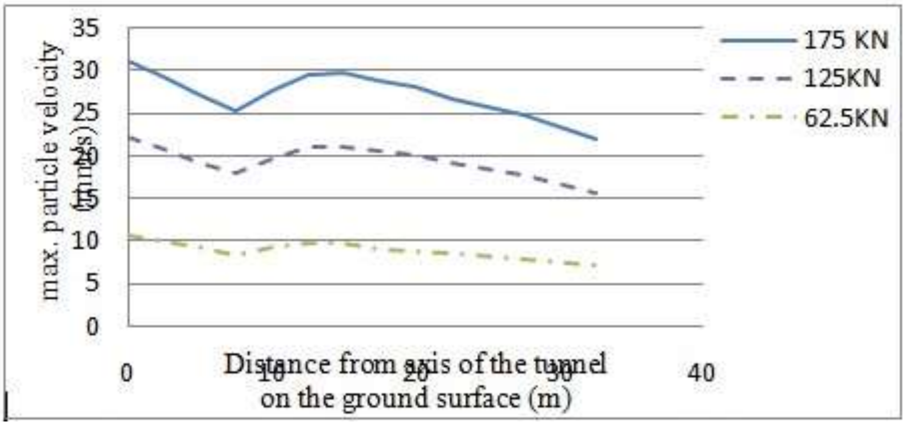

Fig. 14.The effect of wheel force on vertical component of particle velocity on the ground surface.

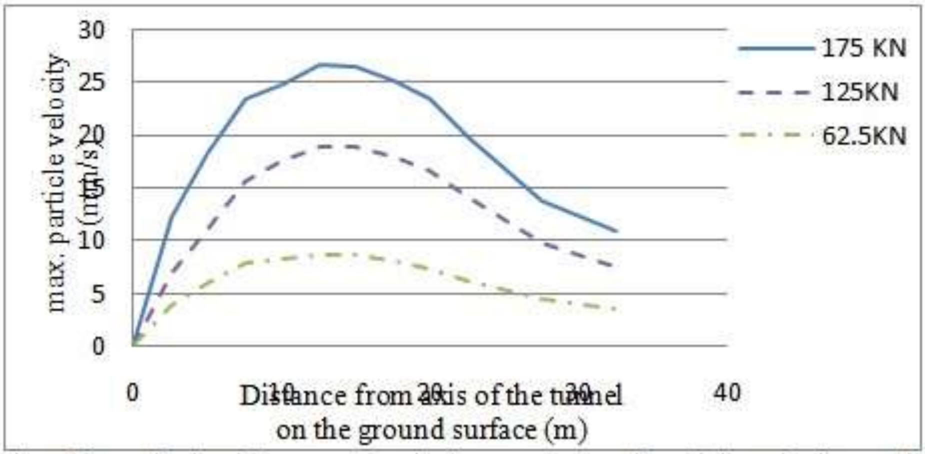

Fig. 15.The effect of wheel force on vertical component of particle velocity on the ground surface.

As mentioned before, a vibration is annoying to humans if the peak ground velocity (PGV) exceeds 2.5 mm/s, while a typical value for the onset of structural damage is 50 mm/s.

The effective parameters of vibrations level can be pointed to the following:

1. Depth of tunnel
2. Characteristics of rail
3. Speed of train
4. Weight of wagon

The vibrations are reduced with increasing depth of the tunnel.Also, the use of absorptive sleepers with higher elastic propertiescan be effective in reducing level of vibrations environment [9].But because of construction of the tunnel at specified depth, cannot be changed factors such as depth of tunnel and characteristics of rail.On the other hand, the results show the effect of wagon weight on level of vibrations is more than train speed.Therefore, the use of light wagon is more effective to reduce level of vibrations. Also capacity of passenger transportation will be reduced with decrease of train speed.

Conclusions

In this research, the effect speed and weight of trainis studied on the surrounding vibration tunnel on the ground surface. To investigate the effect of train motions, speed and weight trains are assumed as the effective factors to calculate the vertical applied load transferred from wagons to the rails in terms of time in a longitudinal model.

1. Increasing train speed reduce period of dynamic load, in other words, frequencies of dynamic load increase so that power of vibration increased on the ground surface. The modeling results show, with increasing train speed, vertical component of particle velocity increased in floor of the tunnel. Also modeling results show that in the general case with increasing train speed, vertical component of particle velocity on the groundincreases, butthis increase do not show a clear trend with distance from axis of the tunnel. Horizontal component ofparticle velocity increases with increasing train speed.

2. With increasing in wheel force, the particle velocity increases in floor of the tunnel and risk of damage to the tunnel lining increases. Also, level of particle velocity increase in two directions (vertical and horizontal) with increases axial force.
3. The results show the effect of wagon weight on level of vibrations is more than train speed.Therefore, the use of light wagon is more effective to reduce level of vibrations.
4. The results show that the level of particles velocity in the vertical direction is greater than the horizontal direction.

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