

Comparative Analysis of Buried Pipe Under Heavy Train Loads

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Abstract: With rapid development of railway transportation and increasing demand of oil and gas in China, the heavy haul train load becomes an important factor that threaten the safe operation of pipe. The mechanical behavior of buried pipe subjected to heavy haul train load was investigated in this study. A finite element model was established to investigate the effect of train load. Finally, the multiple train loads were also discussed. Results show that the high stress area occurs under the train track. In the pipe segment below the track, the top of pipe is under compression and the bottom of pipe is under tension. The cross section of pipe is still circular. The maximum vertical and horizontal displacement are at the top and side of pipe. The maximum von Mises stress, axial strain, and displacement of pipe increase with the increase of train load. Under the multiple train loads, there are two high stress and high strain areas at the top and bottom of pipe. With the increase of multiple train loads, the maximum von Mises stress, axial strain, displacement and ovality increase.

Keywords: Buried pipe, Heavy haul train load, Finite element method, Multiple train loads.

1. Introduction

In recent years, with the large-scale construction of rail transit and the increasing of underground pipeline in various cities, the underground space is becoming more and more crowded. It is more and more common for rail transit lines to be close or cross with buried pipes (Weng 2016). The loads of pipe at the intersection mainly include static loads such as gravity and soil pressure, and live loads such as vehicle traffic load, ground stacking load, temperature load and pipe internal pressure. In vehicle traffic load, train load is very important type that will affect the buried pipes. With the development of China's economy, railway transportation also reflects the characteristics of increased load and speed (Tian 2015), which leads to serious deformation effect of ground surface under the action of train load (Yao 2019). Although the train does not directly roll on the pipe, the transmission of rolling load through the ground and soil will eventually affect the safe operation of the pipes. Thus, conducting mechanical analysis of buried pipe subject to heavy haul train load is of great significance for engineering practice.

A series of literatures are available for mechanical behavior analysis of buried pipes subjected to traffic load. Wang (2021) established a 2D FE model to simulate the polyethylene pipe performance with traffic loading, and some parameters on the effect of bending moment in the pipe were investigated. Fang (2018) investigated the bell and spigot concrete drainage pipe under various working conditions of traffic loads by using FE method, he also discussed the effect of load types, load locations and buried depth on the mechanical responses of pipe. Zha (2019) used numerical simulation to analyze the reliability of gas PE pipe under traffic load, and calculated the stress and stress distribution of buried pipe with single random variables of traffic load. Alzabeebee (2019) investigated the response of buried concrete pipes under the

British Standard traffic load by using finite element model, the effect of the pipe diameter and backfill height on the bending moment in the pipe wall and soil pressure around the pipe were provided.

Previous researches focused on the pipe under soil deformation. Zeng (2019) developed an analytical method of strain and deformation of pipeline, the equivalent spring is used in numerical model to study the effect of mechanical properties of pipeline. Kouretzis (2016) presented an analytical method to estimation of internal forces and strains of buried pipes subjected to permanent ground settlement and heave. Demirci (2018) setup a new experiment to study the effect of reverse faulting on buried pipeline, and the experiment results were compared with FE analysis result to verify the FE model.

Although so many researches had been done, few of them focused on the mechanical behavior of buried pipe subjected to heavy haul train load, and strain analysis is important for buried pipe. Therefore, mechanical behavior of buried pipe subjected to heavy haul train load was investigated in this paper, the finite element model considered train load, train track, sleeper and pipe was established, the interaction between pipe and soil were considered accurately by contact algorithm. These results can provide a theoretical reference for the application of pipe in engineering practice.

2. Materials and Methods

2.1. Materials properties

A linear isotropic strain hardening model had been used in steel pipe material, the numerical results were obtained for the X65 steel pipe in this study. The yield stress is 448.5MPa (Vazouras et al. 2010), the Young's modulus is 210GPa, the Poisson's ratio is 0.3, and the density is 7800kg/m³.

The soil and ballast were described as the Mohr-Coulomb

model, characterized by the density ρ , the cohesion c , the friction angle f , the elastic modulus E , and Poisson's ratio m , the dilation angle was assumed equal to zero for all cases considered in this paper (Vazouras et al. 2012). It was assumed that soil and ballast are isotropic material and do not contain gravel or pore. The train track and sleeper were described as linear elastic model (Huang 2019). Type 75 heavy rail was used for the train track, and type III reinforced concrete is used for sleeper, the parameters were given in Table 1 (Huang 2019; Ling 2020; Yang 2009).

2.2. Finite element model and boundary conditions

The load generated in the process of train operation mainly comes from the interaction between wheel and rail. In this study, the C80 coal heavy haul train with designed axle load of 300kN was considered, and the vertical load was adopted

to analysis the mechanical performance of buried pipe.

The finite element model was established by general nonlinear finite element program. The diameter and wall thickness of pipe were set to be true value which were used in engineering. The pipe diameter is 660mm, the pipe wall thickness is 8mm. The soil around the pipe is the same length with pipe, the whole soil model is set to be 16m×8m×5m. The distance between pipe center and ground is 1.5m. The cross section of train track was simplified as a rectangle, the width of cross section is 15cm, and the height is 15cm (Huang 2019). The standard gauge of 1.435m was adopted for rail gauge (Industry Standard of the People's Republic of China 2017). The cross section of sleeper was simplified to a cuboid, the length is 2.5m, the width is 0.3m and the height is 0.23m. The longitudinal spacing of sleepers along the track is 0.6m (Huang 2019). Schematic diagram of geometric model is shown in Figure 1.

Table 1. Material parameters

	$\rho(\text{kg/m}^3)$	$E(\text{MPa})$	μ	$\phi(^{\circ})$	$C(\text{kPa})$
Soil	190	18	0.4	18	20
Ballast	1950	190	0.25	34	80
Train track	7810	210000	0.3	-	-
Sleeper	2400	35000	0.17	-	-

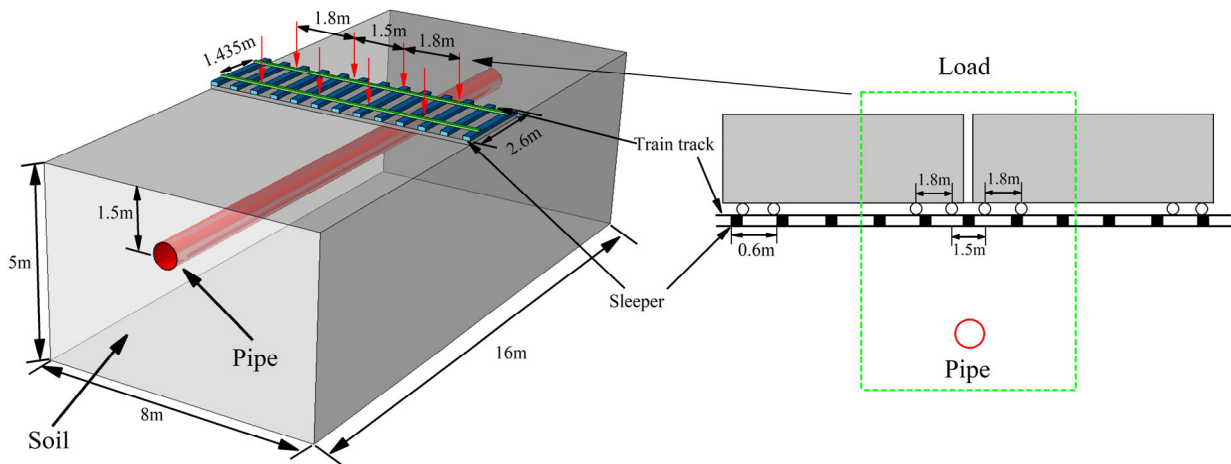


Figure 1. Schematic diagram of geometric model

In the numerical model, the load imposed by the train corresponds to the train wheelset in space, and the concentrated force was applied on the wheel rail contact point to describe the interaction force between wheel and rail (Huang 2019). The moving load of the train was equivalented to the static load. The static wheel load was calculated from the axle load of the train in the code, and then multiplied by the coefficient, which is about 1.3 times of the maximum static load to simulate the train load (Ling 2020; Industry Standard of the People's Republic of China 2017). Take the position of the joint of the train analysis, where the wheels and load were densely distributed, there were four sets of wheels, as shown in Figure 1. The distance between two adjacent wheels in the same train carriage is 1.8m, and the distance between two adjacent wheels in the different train carriage is 1.5m (Huang 2019; Industry Standard of the People's Republic of China 2017).

The whole model was calculated by 1/2 model considering the symmetry of load and geometry. In the numerical analysis, the x - y and y - z surfaces of the soil was restrained in z direction and x direction. The bottom surface (the underside x - z surface)

of the soil was restrained in the xyz direction, the topside x - z surface was set to be free. Symmetry constraints were used for symmetry surfaces. The Dynamic/Explicit analysis was used to simulate the load process. The numerical analysis is conducted in three steps: the gravity loading step, the internal pressure step and the train load step. In the first gravity loading step, gravity load was applied on the whole model. In the internal pressure load step, internal pressure was applied on the inner surface of pipe. In the train load step, train load was applied on the train track in y direction. The finite element model is shown in Figure 2.

Interaction between soil and pipe was simulated by using surface to surface contact algorithm, which allows separation of soil and pipe. The interface friction was described by friction coefficient, the value of coefficient is considered equal to 0.3.

The soil, sleeper and train track were all simulated by eight-node reduced integration elements (C3D8R), the pipe was simulated by four-node shell elements(S4R). The mesh method used in this study is as follows: In the circumferential direction of pipe, it was discretized into 40 equal sized

continuum elements. In the longitudinal direction of pipe, a fine mesh (40 equal sized elements) was used for 1.25m long pipe segment in axial direction of the pipe under the train track, while a coarse mesh was used for the pipe in the end.

3. Single Train Load Analysis

The load on the pipe induced by heavy haul train is random in true cases. In this section, mechanical behavior of buried pipe with different train load were investigated. Figure 2

shows the von Mises stress distribution of pipe with different train loads. With the increase of train load, the high stress area extends along the axial direction of pipe, the maximum stress of inside and outside surface of pipe increase, and the change rate increases slightly. The stress of inside surface is larger, and the maximum stress located in the inside surface of top of pipe. When train load increases from 150kN to 350kN, the maximum stress increases about 60MPa. Therefore, the buried pipe may be dangerous when train load is larger.

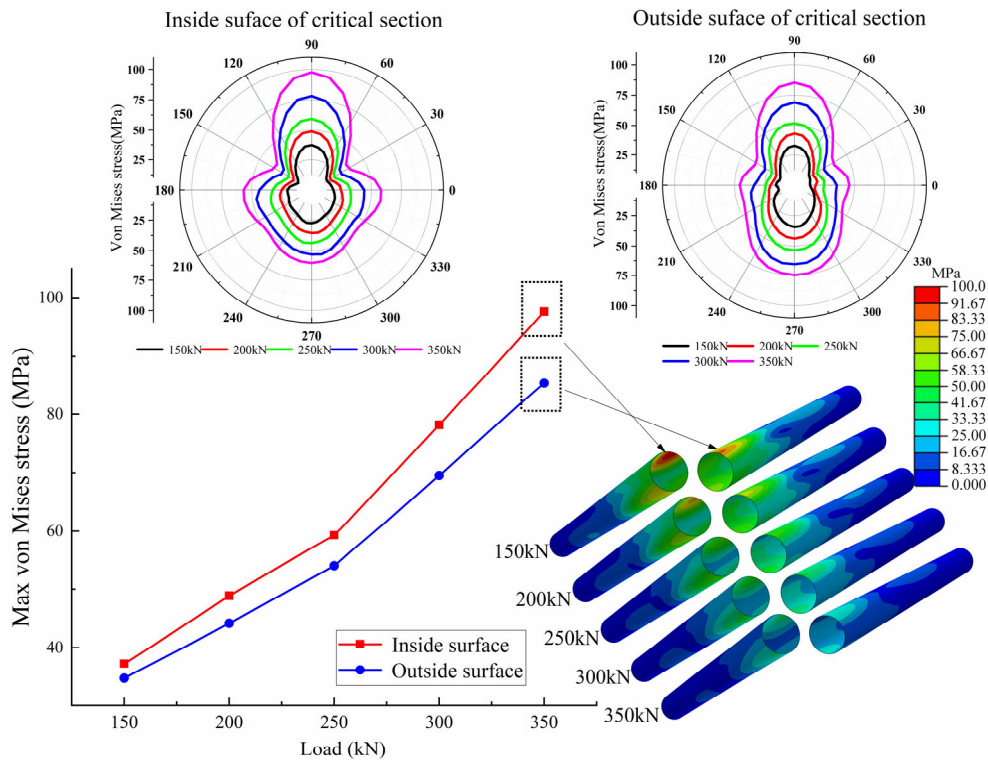


Figure 2. Von Mises stress distribution of pipe with different loads

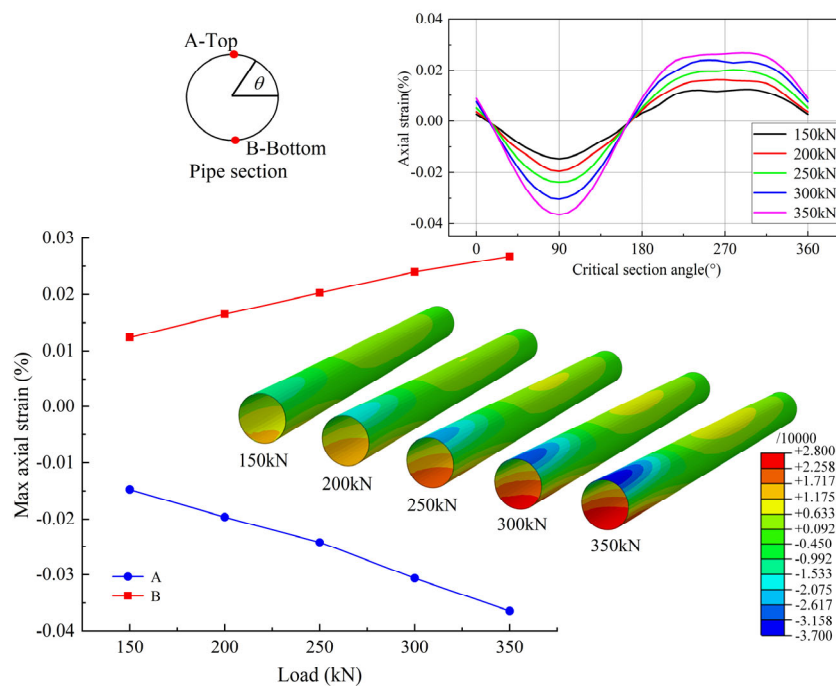


Figure 3. Axial strain distribution of pipe with different loads

Figure 3 shows the axial strain distribution of pipe with different train loads. With the increase of train load, the

maximum strain of top and bottom of pipe increase, and the change rate basically unchanged. In the middle of pipe, the

top of pipe still under compression and the bottom of pipe is under tension. Additionally, the axial strain of the end of pipe is very small when train load is 150kN, the pipe bending degree is too small.

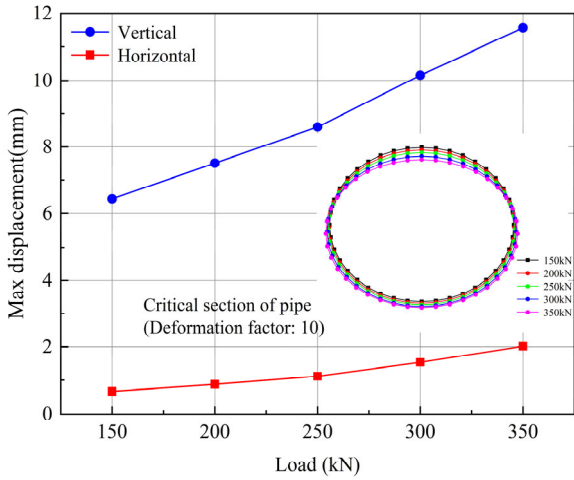


Figure 4. Displacement of pipe with different loads

Figure 4 shows the displacement of pipe with different train loads. When train load increases from 150kN to 350kN, the maximum horizontal displacement increases a little, while the maximum vertical displacement increases obviously, which changes from 6.4mm to 11.5mm. The critical section of pipe trends to be slightly oval with the increase of train load. The vertical displacement of top of pipe is larger than the bottom of pipe, because the train load is mainly sustained by the top of pipe, the pipe deforms uniformly in the circumferential direction. Additionally, with the increase of train load, the vertical displacement of top of pipe increases obviously.

4. Multiple Train Loads Analysis

In practical engineering, train group is widely used, so that there are many groups of tracks with close distance on the ground. In this section, mechanical behavior of buried pipe with different multiple heavy haul train loads were investigated. Figure 5 shows the schematic diagram of buried pipe with multiple train load. The whole model was used, the distance between multiple loads is 4m, the buried depth of pipe is 1.5m, the diameter of pipe is 660mm, and the thickness of pipe is 8mm. Geometric and material parameters are declared in section 2. The two different train loads were described by Load-1 and Load-2, which ranging from 150kN to 350kN.

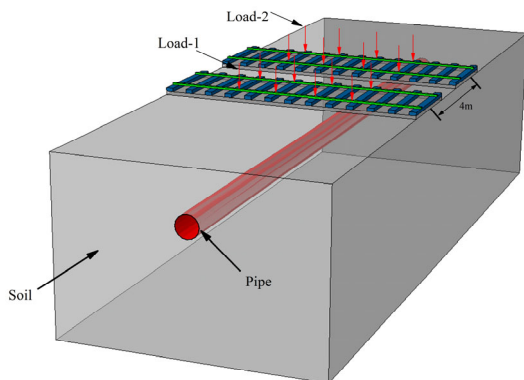
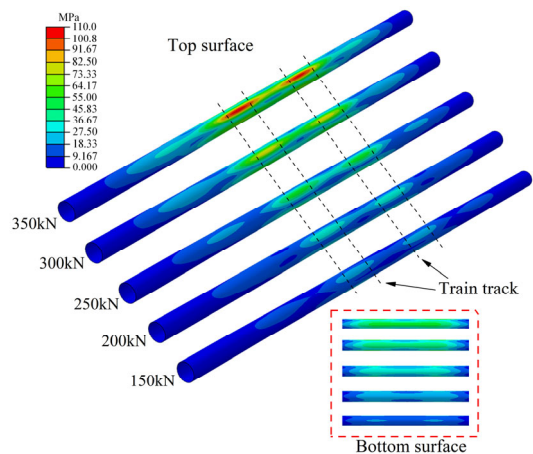


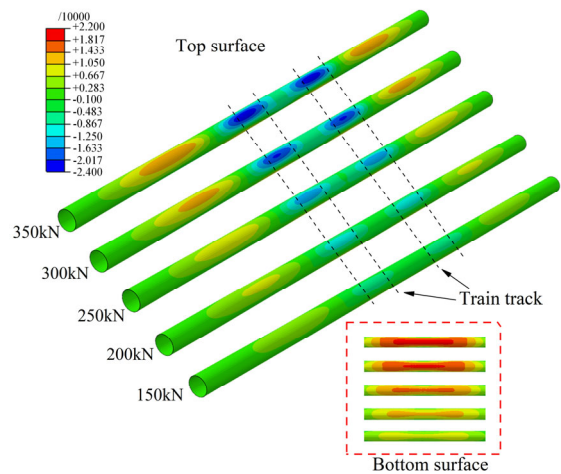
Figure 5. Schematic diagram of buried pipe with multiple train load

When the Load-1 equals to Load-2, and the load ranging from 150kN to 350kN, the stress-strain distribution of pipe is shown in Figure 20. In Figure 6(a), there are two high stress area at the top and bottom of pipe, each of high stress area is located under the train track. When load-1 and load-2 are larger, the high stress areas trend to merge together. But the high stress area is separated when load is small. The difference between the maximum stress of pipe with same multiple train loads and the maximum stress of pipe with single train load is very small. Therefore, multiple train loads will affect the stress area of pipe, but it has little effect on the maximum stress of pipe. In Figure 6(b), the axial strain distribution is similar with the stress distribution. Two high strain area at the top and bottom of pipe, the high strain area gradually separates when the train load decreases.

Figure 7 shows the displacement of pipe with same multiple train loads. With the increase of multiple train load, the maximum vertical and horizontal displacement increase, and the trend is similar to the single train load. However, the maximum displacement of pipe with multiple train loads is larger than single train load. This is because deformation area of pipe with multiple train loads is larger than single train load, and the bending area of the pipe is larger. Additionally, the variation of vertical displacement is more obviously. And with the increase of multiple train loads, the ovality of the critical section of pipe increases.



(a) Von Mises stress distribution of pipe



(b) Axial strain distribution of pipe

Figure 6. Stress-strain distribution of pipe with same multiple train loads

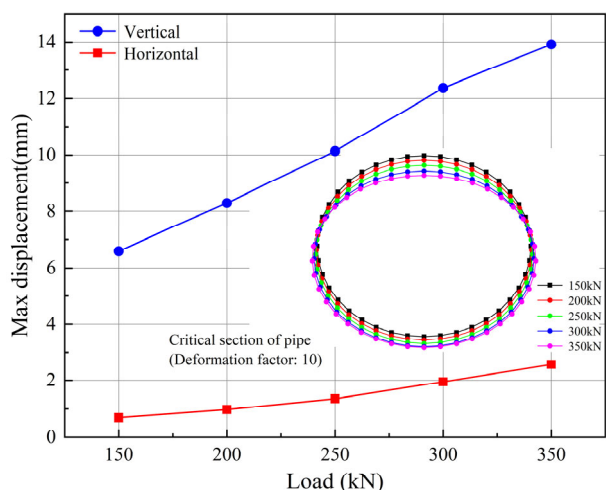


Figure 7. Displacement of pipe with same multiple train loads

5. Conclusions

Mechanical behavior of buried pipe subjected to heavy haul train load were investigated in this study. The main conclusions are as follows:

(1) High stress area occurs under the train track, and the shape of high stress area is ellipse. In the pipe segment below the track, the top of pipe is under compression and the bottom of pipe is under tension. The strain of inside and outside surface of pipe is similar. The cross section of pipe can be kept circular. The maximum vertical and horizontal displacement are at the top and side of pipe respectively. The maximum von Mises stress, axial strain, and displacement of pipe increase with the increase of train load.

(2) There are two high stress and high strain area at the top and bottom of pipe when pipe subjected to multiple train loads. When multiple loads are larger, the high stress and high strain areas trend to merge together. The difference between the pipe with same multiple train loads and the pipe with single train load is very small. With the increase of multiple train load, the maximum displacement and ovality increase, and the variation of vertical displacement is more obviously.

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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