Research on the damage of heavy vehicles to the pavement

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Abstract. The dynamic load of heavy vehicles accelerates the destruction of the pavement tremendously. Most of the current designs of the pavement structure consider the mechanical behavior in the static load effect of the vehicle as the research object, which is basically suitable in the case of low load and low speed. With the improvement of vehicle load and running speed, the difference between static load model and the actual impact on the ground in the process of vehicle driving grows bigger and dynamic characteristics of the ground structure is far from what the static characteristics can describe. Researches on the mechanical behavior of the interaction of vehicle-pavement coupling system have attracted people's attention in recent years. This paper presents a systematic research on the effect between vehicle and pavement under the heavy vehicle dynamic loads, which focuses on driving structure parameters, driving speed's dynamic load on the pavement and the mechanical behavior resulting in the pavement stress and strain response and also on the optimization of structural parameters of vehicle without reducing the dynamic load on the ground but not declining the ride comfort, aiming at revealing the internal relations and rules between the pavement and the vehicle, which is of certain significance in guiding the design of pavement structure and heavy vehicle and has certain practical significance to prolong the service life of the pavement.

Introduction

Since the reform and opening up, with the rapid development of China's economy, transportation industry has made rapid development. As the Ministry of Transportation recently announced, up to the end of the year, the total highway mileage is million kilometers, million kilometers more than the previous year; the national highway mileage is million kilometers, accounting for the total mileage of highway, the percentage points over the previous year. The second-level and higher highway mileage is million kilometers, accounting for the total road mileage, percentage points more than the previous year. According to the level grouping of road, the highway mileage of each level is respectively million kilometers for expressway, million kilometers for the first-level highway, million kilometers for the second-level highway. Most of them are black pavements. Because asphalt pavement has smooth surface, no seams, riding comfort, low noise, short construction period, low cost and convenient maintenance, it is widely applied to the construction of the high-level highway.

As the fast and comfortable freeway widely open in traffic, highway transportation has also been boomed. At present, the freight volume on the highway exceeds that on the railway, becoming the main means of freight transport. And passenger transport through highway accounts for almost of the total. With the increase of highway transportation volume, the limits of axis load quality all over the world and limits of the car's total quality are improved. In the 1980s, International Transport Federation raised the axle load quality limit of single axle double wheels from the double axle load

quality limit to the total quality of the vehicle. The Over-Limit Transport Vehicle Management *Regulations* launched by the Ministry of Transportation in China has new provisions on the vehicle axle load quality, saying that the load applied to the pavement caused by the vehicles with "single axle single wheel load quality, single axle double wheel load quality and double axle double wheel load quality" in the process of driving is not equal to the static load but to the changing load, namely, dynamic load. At present, the reasonable limit of high level pavement with single axle double wheel load quality is tons, but the existence of the dynamic load makes the actual axle load that the pavement bears far greater than the value, according to the four methods flat obtained from the test. The dynamic load of heavy vehicles accelerates the destruction of the pavement tremendously. Most of the current designs of the pavement structure consider the mechanical behavior in the static load effect of the vehicle as the research object, which is basically suitable in the case of low load and low speed. With the improvement of vehicle load and running speed, the difference between static load model and the actual impact on the ground in the process of vehicle driving grows bigger and dynamic characteristics of the ground structure is far from what the static characteristics can describe. Researches on the mechanical behavior of the interaction of vehicle and pavement coupling system have attracted people's attention. In this respect, the countries in the world, especially in western countries, have carried out plentiful theoretical research work. For example, the United States invested billions of dollars to carry out the plan, at the end, Congress added billion dollars for the long-term observation for the pavement performance, and most of these funds were used for studies on the interaction between vehicle and pavement, namely, the study on dynamic performance of the pavement. Researchers of the pavement, from the perspective of the pavement mechanics, regard the vehicle as a static load to analyze some problems in the design of pavement, but the dynamic load of the vehicle and the dynamic response of the pavement generated by it are not considered. The staffs who are engaged in researching dynamics generally just treat the road as a random distributed external incentive but seldom involve the research on the effect that the vehicle has on road and the damage that the vehicle does to the road when driving.

Researches on the mechanical behavior of the interaction of vehicle-pavement coupling mechanics behavior interaction have attracted people's attention in recent years. It is mainly to implement analysis research on the vehicle, the road and the interaction between them, from the perspective of mechanics, it provides a theoretical basis for the design of asphalt pavement in the condition of high speed and heavy load, so as to solve the problems of early damage and short service life of the high-level asphalt pavements. Experts and scholars in their respective fields have been conducting deep researches on the vehicle and the road themselves, but integrating them as a system, although there are many beneficial discussions and researches, shows no obvious effect, especially the research on changes in the structural parameters and the velocity of the vehicle generating the mechanical response of pavement. At present the domestic and overseas researches on the damage that the vehicle does to the pavement are mainly conducted in the following aspects: the pavement mechanics research, vehicle-pavement coupling system and dynamic load calculation of the vehicle.

Research on the pavement dynamics in our country began in the 1980s, followed by more and more scholars. The research on this problem is mainly in Tongji University, Southeast University, Chang'an University and the Air Force Engineering Institute. Assisted by Chinese Institute of Computing Technology Research Institute, Tongji University Research Institute of Highway implemented a relatively comprehensive calculation on the stress and displacement of the

interformational succession and interformational sliding in the double-layer and triple-layer elastic system. Afterwards, the stress and displacement under horizontal load were calculated and the superposition principle was used to calculate stress and displacement values under the vertical and horizontal loads. In recent years, due to the increase of the highway investment, especially the rapid growth of the expressway mileage, the research of pavement mechanics in China has been greatly developed.

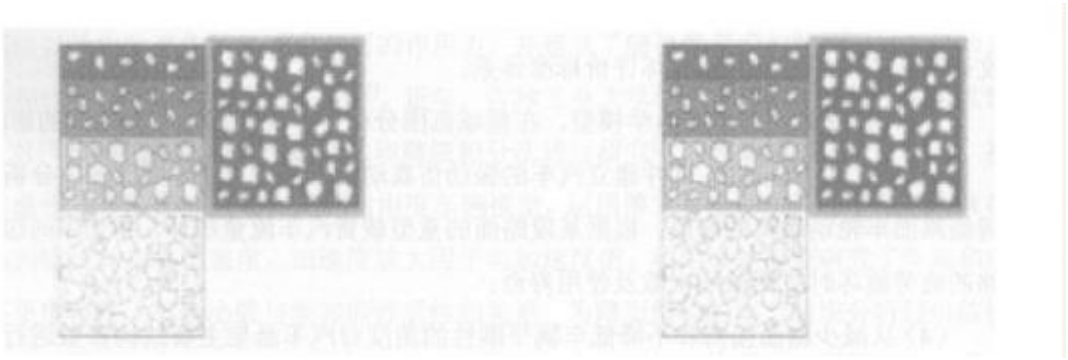
Among other countries, the United States, a country with the world's most powerful economy and technology and most developed road transport and air transport, invested billions of dollars for the development of " strategic highway research program ", referred to as the plan. As the plan ended, Congress invested billions of dollars for the long-term pavement performance observation, with most of the funds on researches of pavement dynamics. The European community is enhancing the research in this area, for example, Department of Engineering Mechanics in the University of Cambridge has made some contributions. From the essays published on the international most prestigious authoritative publication and various international journals of the American Society of civil engineers and the American Society of mechanical engineers, it can be seen that this field has become an international concern.

From the perspective of practical application, as for the gradual increase of high speed and heavy load vehicles in the current transportation trend, the thesis carries out a systematic research on the interaction between the vehicle and pavement under heavy vehicle dynamic loads, focusing on driving structure parameters, driving speed's dynamic load on the pavement and the mechanical behavior resulting in the pavement stress and strain response and also on the optimization of structural parameters of vehicle without reducing the dynamic load on the ground but not declining the ride comfort, aiming at revealing the internal relations and rules between the pavement and the vehicle, which is of certain significance in guiding the design of pavement structure and heavy vehicle and has certain practical significance to prolong the service life of the pavement.

Methods

The road itself is a kind of bearing structure, whose function is to transfer the repeated wheel impact load during its life cycle to natural soil. Therefore, the road is not only to form a simple road surface to ensure the vehicle ride comfort, but also must be strong enough to support the vehicle. As a kind of bearing structure, it must ensure to work normally under a variety of conditions.

The road structure generally comprises a surface layer, base and sometimes even sub base and soil etc. According to the material of the surface layer it can be divided into flexible pavement and rigid pavement. The surface layer of a flexible pavement is one or more layers of flexible material of asphalt concrete, while base is generally supported by grit and gravel, whose basic structure is shown in Fig. 1.



the flexible pavement structure (asphalt pavement, asphalt adhesion layer, asphalt bottom)

the rigid pavement structure (PCC surface layer, seal, gravel bottom)

Fig. 1 basic structure

The surface layer of rigid pavement is concrete materials portland cement concrete; the surface has seams or reinforcing rebar; the base is supported by grit and gravel, whose basic structure is shown in Fig. 2.

As for a given road roughness input, establish the vehicle model to implement simulation analysis on the random dynamic loads of the wheels. Through the simulation analysis, acquire the numerical solution of the vehicle-road interaction.

According to the references (), assumptions of the model are as follows:

1. The body is rigid and symmetrical to the vertical plane and the front and rear axles are regarded as particles.

2. Left and right wheels are stimulated by the same road roughness.

3. Vehicles ride on straight lines, and tires always keep in contact with the ground without jump.

4. The body only has vertical vibration and pitch vibration.

5. Pavement displacement input function works on the center of the contact point of the tire and the road.

6. The contact of the tire and road surface is regarded as point contact.

According to the above assumptions, the vehicle model can be simplified as a plane model of four degrees of freedom. Four degrees of freedom are the vertical vibration of vehicle body, pitching vibration and vertical jumping of front and rear wheels. The established model is shown in Fig. 2.

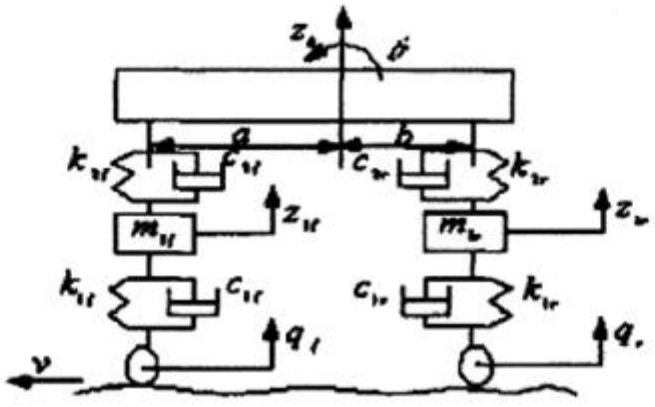


Fig. 2 1/2 plan simplified model of the vehicle

The differential equations of the system:

$$(M)\{X\} + \{X\}(C) + (K)\{X\} = \{F\}(T)$$

When the vehicle drives on the rough road, road roughness and vehicle speed directly affect the vehicle vibration characteristics value and random dynamic load of the wheel on the ground, making the wheel load changed.

Considering the research requirements of vertical vibration, the paper adopts a vibration model. In the vehicle-road system, the damage of the pavement is mainly caused by the reduction behavior of the contact between the tire and ground. In the simulation process, the main concern is the forced vibration and mechanical vibration model at vertical direction caused by vehicles stimulated by road roughness .

1. The wheel of the car at any time should not jump off the road,

2. Ignore the influence of the other wheel on the same axle on the wheel vibration to be studied, namely, the roughness functions of the road driven on by left and right wheel are equal.

In traditional automobile design, the main design parameters of the suspension ---- stiffness and damping are mainly determined to meet the requirements of vehicle ride comfort, without considering the influence on pavement damage. Especially with the development of highway traffic, more and more heavy vehicles are driving on the road, so the problem of the road damage caused by heavy vehicles can not be neglected. The paper implements the optimization analysis of heavy automobile suspension from the angle of reducing pavement damage in order to provide theoretical reference for the design of heavy vehicle suspension.

In addition to affecting the road dynamic load of the vehicle, stiffness and damping of the suspension also has an impact on the body vertical acceleration, suspension dynamic deflection and other ride comfort index. In order to ensure that when the optimization design is conducted for the purpose of reducing the damage to the road caused by the vehicle, the vehicle ride comfort and safety of strength are not reduced, the following two constraints are established:

1. suspension dynamic deflection constraints

2. body vertical vibration acceleration constraints

Conclusion

Analysis and research on the interaction between the vehicle and the road is an important topic both in the field of road research and vehicles research which is attracting more and more people’s attention. The paper studies the vehicle-pavement interaction and makes some conclusions as follows.

1. This paper systematically analyzes and studies the evaluation of domestic and foreign current road damage and points out the deficiencies of the existing index. The paper combines the foreign road fatigue damage evaluation index based on the fatigue fracture theory of single vehicle driving on the road with the daily cycle times of the specific situations of China's road transport to improve the evaluation index and get the calculation method of the service lift of the pavement.

2. Through the frequency domain analysis of 1/2 vehicle vibration model, it is shown that the dynamic load that the road bears directly depends on the pavement roughness and the speed of the vehicle. Good pavement is under smaller dynamic load while bad pavement is under larger dynamic load. The slower the vehicle is, the smaller dynamic load the pavement bears. Both the increase of tire stiffness coefficient and the reduction of the suspension damping coefficient will make the wheel dynamic load that the pavement bears increase.

3. Software is used to establish the vibration model of the axle vehicle to analyze the impact that wheels have on the pavement at different speed and on roads on different levels in the time domain. Obtain the peak value of the wheel dynamic load that the pavement bears and apply road fatigue damage evaluation index based on the fatigue fracture theory of single vehicle driving on the road to analyze the strain cycle times of a certain section of the road fatigue damage under the vehicle dynamic load. After comparison and analysis, when the vehicle is overloaded, the service life of the pavement decrease to half of the original lifespan.

4. The calculation of fatigue damage times can provide certain materials and methods for the future study of highway damage.

5. From the perspective of reducing the pavement damage, the optimization design and analysis of heavy automobile suspension is implemented. The optimization results show that one of the main reasons of heavy vehicles on road damage is that the rear suspension damping is too small. Therefore, the increase of rear suspension damping is the powerful measure to reduce the vehicle dynamic load.

Problems and Prospects

Due to time limitation, as for the study on the vehicle-pavement effect, there are still many aspects needing further research and perfection.

1. The mechanics model of the vehicle vibration should be improved. At present, only the axle vehicle vibration model is established. In the future work, multi-axis vehicle model should be established to analyze the dynamic load and build a database, providing convenience for the calculation of other highway damage.

2. A reasonable dynamic load test of the vehicle on the road should be designed. Compare the experimental data with simulation results in order to draw more accurate conclusions.

3. In the road model, dynamic deflection quantity should be considered.

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