Dynamic Response Analysis of Cement Concrete Pavement under Different Vehicle Speeds

Tian Xiao[1] Ji-shu Sun[2] Xiao-hua Wang[1] Zhao-xia Chen[2]

[1] Senior Engineer, Tianjin Municipal Engineering Design & Research Institute, 239 Yingkou Street, Tianjin 300051, People's Republic of China; PH (86)022-27815311; E-mail:sjshebut@126.com
[2]Doctoral student, Dept. of Civil Engineering, Hebei University of Technology, Guangrong Road #8, Tianjin 300130, People's Republic of China; Tel:(86)022-60435980; E-mail: sunjishu76@126.com

ABSTRACT: Through a finite-element model developed in the ANSYS platform, the stress-strain properties of concrete pavement under dynamic loads were studied and the affecting laws of different speeds on the stress-strain properties of concrete pavement were determined in this paper. Analysis results indicate the significant difference between static loads and dynamic loads on concrete pavement performance and deterioration. Vehicle speed has a significant effect on the stress-strain properties of concrete pavement. Furthermore, slower vehicle speed has a greater effect than faster vehicle speed. This research finding can provide us with a more accurate grasp of the actual working conditions of concrete pavement, and provide some guidance to the structural design of concrete pavements.

INTRODUCTION

While there has been a great deal of research conducted on concrete pavement design and analysis under static loads, only a very limited number of studies have been carried out on dynamic response of concrete pavements. Vehicular loads have been considered as static loads in concrete pavement design and performance analysis. This method can only be applied on the concrete pavement performance analysis where vehicle speed is very slow or stopped. However, in fact, the concrete pavement is working under dynamic loads. We must determine the influence of different speeds on the concrete pavement mechanical properties.

Darestani et al. (2007) constructed a fully-instrumented concrete pavement test section and tested under quasistatic and dynamic truck loadings. They present the significance of dynamic amplification in concrete pavement design. Dong et al. (2009) analyzed the dynamic response of three directional strains in asphalt pavement under moving vehicle loads, and drew out the time histories of three directional strains in the pavement structure. Chatti et al. (1994) carried out the analytical studies of concrete pavements under dynamic loads. Bhatti and Stoner (1998), Kim et al. (2002) showed that speed has a significant effect on slab deflection. However, a greater stress can be captured in concrete pavements if a static analysis of concrete pavement is performed. Analytical studies on concrete pavements under moving axle group loads carried out by Darestani et al. (2006a) showed that vehicle speed has a significant effect on responses of concrete pavement even if the pavement has a smooth top surface.

Through a finite-element model developed in the ANSYS platform, the stress-strain properties of concrete pavement under dynamic loads were studied and the affecting laws of different speeds on the stress-strain properties of concrete pavement are presented in this paper. Analysis results indicate a significant difference between static loads and dynamic loads on concrete pavement performance and deterioration. Vehicle speed has a significant effect on the stress-strain properties of concrete pavement. Furthermore, slower vehicle speed has a greater effect than faster vehicle speed. This research finding can provide a more accurate grasp of the actual working conditions of concrete pavement and provide some guidance to structural design of concrete pavements.

ANLYSIS METHODS AND MECHANICAL FEATURES OF THE CEMENT CONCRETE PAVEMENT

Analysis Methods

There are many pavement structure analysis methods. The two major ones are the analytical method and the finite element method. The analytical method is widely used in the calculation of the elastic layered system of the pavement structure. However, it cannot be imposed with complex three-dimensional boundary constraints. There are many limitations in the analysis of real pavement structures. It is difficult to consider some actual existing conditions in multi-layer pavement structure computation. Another major pavement structure analysis method is based on the finite element method. Through a finite-element model developed in the ANSYS platform, the configuration and various boundary conditions of the three dimensional pavement structures are modeled. The analysis results of pavement structure using the finite element method are more accurate and closer to the actual situation. Accordingly, the finite element method is used in the stress-strain properties analysis of concrete pavement under dynamic loads in this paper.

Mechanical Features of the Pavement Material

The concrete pavement analyzed in this paper consisted of four layers; the concrete surface layer, the cement-stabilized macadam base course, the graded aggregate subbase, and, the subgrade. The mechanical features of the pavement material are presented in Table 1.

Table 1．The Mechanical Features of the Concrete Pavement Material

Layer Name	Thickness (m)	Elasticity (MPa)	Poisson Ratio	Density (kg/m^3)
Concrete surface	0.24	3e+10	0.15	2800
Base (cement-stabilized macadam)	0.18	2e+09	0.20	2500
Subbase (graded aggregate)	0.20	3e+08	0.25	2100
Subgrade	--	3e+07	0.35	1800

MODELING PROCEDURE

Modeling and Grid Division, Boundary Condition

The three dimensional model of the concrete pavement structure was developed in the ANSYS platform. Concrete surface size selected was 5.0m in length and 4.0m in width. Unit solid 45 and surface effect unit 154 were selected in the ANSYS software. For better layer contact simulation of the concrete pavement, 3D surface to surface contact unit Contal 74 and unit Targe170 were used in the analysis. Assigning the selected units with the established parameters, dividing the surface layer into rectangular units of 0.2m*0.2m using the Mapped Division method of the ANSYS software, the condition was prepared for the following simulation of moving load under the different vehicle speeds.

The boundary condition is a very important factor in pavement stress and strain analysis. In this model, X axis is the driving direction and Y axis is the road width direction. Boundary conditions are three direction fixed constraint in the bottom of the subgrade, X direction fixed constraint in the two lateral sides parallel to X axis, and Y direction fixed constraint in the two lateral sides parallel to Y axis.

Loading Pattern

Because the contact shape of the tire with pavement is very complex, for the convenience of the finite element modeling and computation, the shape of the tire-pavement contact area is assumed to be rectangle of 0.2m in length and 0.2m in width in this paper. The tire load on the pavement is 0.7MPa. A sketch map of the two-wheeled load is shown in Figure 1.

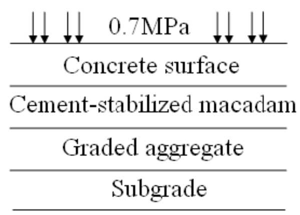


FIG. 1. Sketch map of two wheeled load

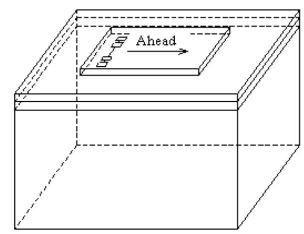


FIG. 2. Sketch map of moving load

Firstly, the analysis type must be changed into transient analysis through the FULL method provided by ANSYS software before applying the moving load. Boundary conditions are then applied on the finite element of concrete pavement structure. The moving loads are simulated through multi-steps load in ANSYS software. The stress and strain situation of the concrete pavement under different vehicle speeds could be simulated by changing the load time on the surface of each unit. The simplified moving load is shown in Figure 2.

RESULTS ANALYSIS

Stress Distribution Analysis under Moving Loads

For an example, the stress distribution graph of X direction was analyzed. The loads selected in the analysis were four times point load, and the vehicle speed was 60km/h. The result is shown in Figure 3.

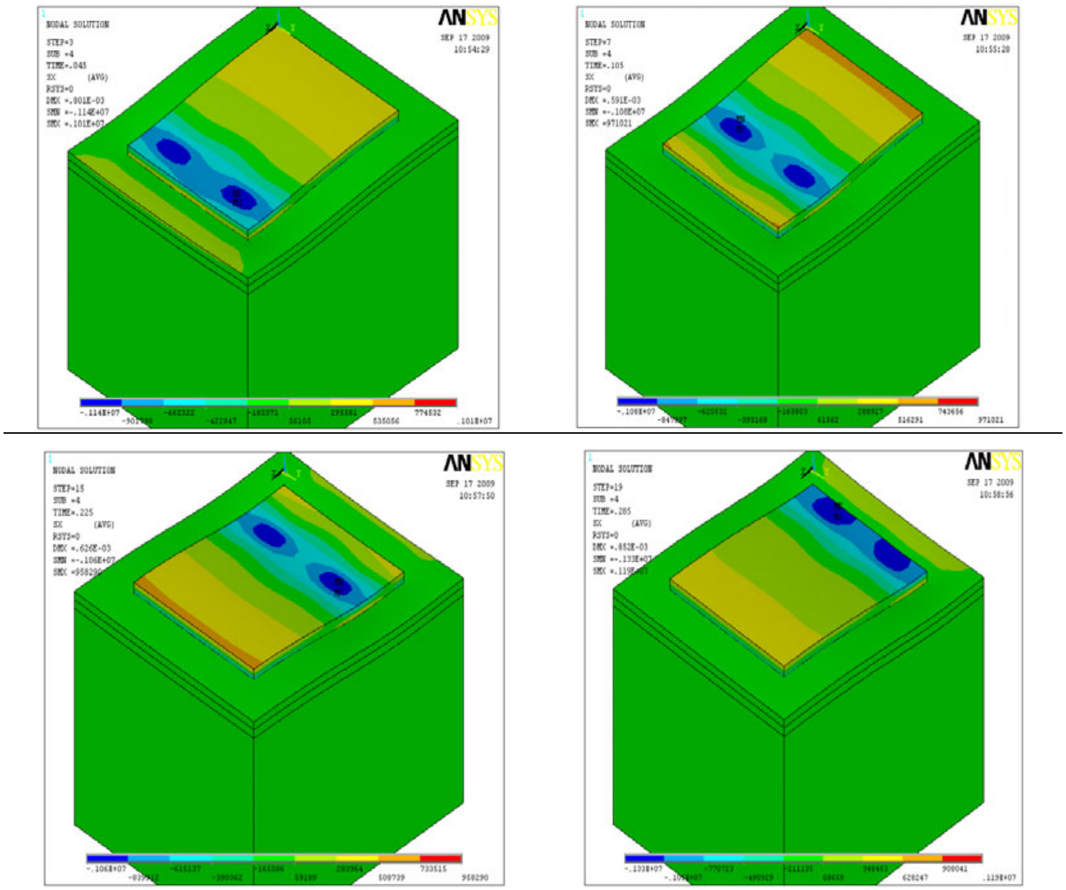
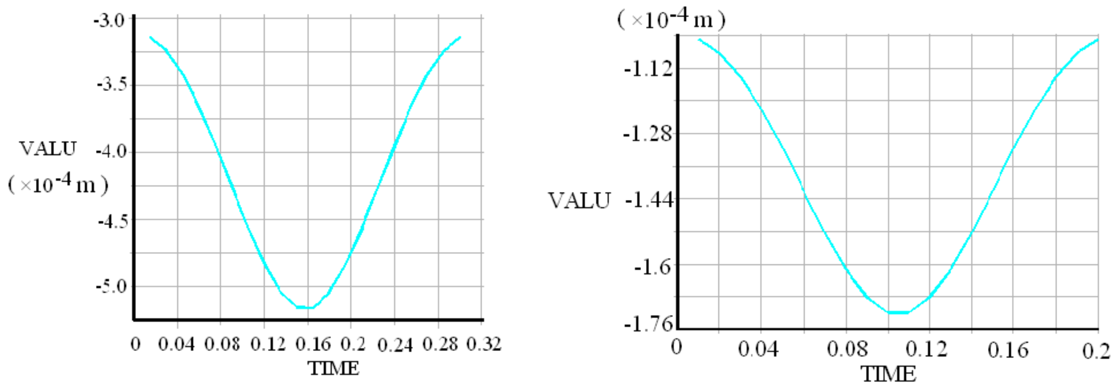


FIG. 3. Stress distribution graph under vehicle speed was 60km/h

The stress region in blue was the vehicle load region, the region moved ahead represented that the vehicle load moved forward. There was compressive stress from the tire in the blue color region, and tensile stress on the bottom of the concrete slab. Moreover, the tensile stress on the bottom of the concrete slab was always the biggest one in the pavement structure under the moving loads.

Vertical Displacement of the Slab

Taking the central point of wheel track on the concrete surface as the viewpoint, the vertical displacement was observed at various speeds of 30, 60, 100 and 120km/h. The relation curve of vertical displacement with time under vehicle speed of 60 and 120km/h are shown in Figure 4.



Vehicle speed 60km/h Vehicle speed 120km/h

FIG. 4. The changing curve of vertical displacement with time

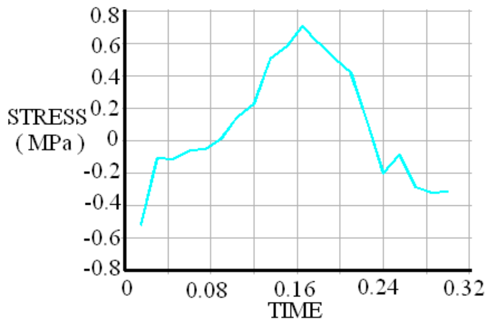
From Figure 4, we can see that when the loads begin to move forward, the vertical displacement of the viewpoint will increase and the vertical displacement reaches its maximum value when the loads move to the right above the viewpoint. The occurring time and value of the vertical displacement would be different under different vertical speeds. The maximum values of vertical displacement at speeds of 30, 60, 100 and 120km/h are shown in Table 2.

Table 2 . The Maximum Value of Vertical Displacement at Different Speed

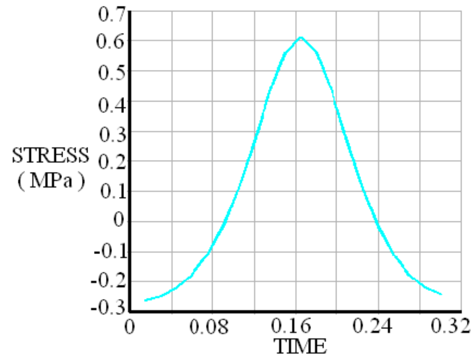
Speed (km/h)	30	60	100	120
Vertical Displacement (mm)	0.607	0.515	0.332	0.175

Tensile Stress on the Bottom of the Concrete Slab

Taking one point on the bottom of the concrete slab as the viewpoint, the tensile stress was observed at speeds of 30, 60, 100 and 120km/h. The relation curve of tensile stress with time under vehicle speed of 60 and 100km/h are shown in Figure 5.



Vehicle speed 60km/h



Vehicle speed 100km/h

FIG. 5. The changing curve of tensile stress with time

From Figure 5, we know that when the loads begin to move forward the tensile stress in X direction of the viewpoint will increase, and the tensile stress reaches its maximum value when the loads move to the right above the viewpoint. The occurring time and value of the tensile stress would be different under different vertical speeds. The maximum values of tensile stress on the bottom of the concrete slab at speeds of 30, 60, 100 and 120km/h are shown in Table 3.

Table 3 . The Maximum Value of Tensile Stress on the Bottom of the Concrete Slab at Different Speed

Speed (km/h)	30	60	100	120
Tensile Stress (MPa)	0.953	0.701	0.617	0.476

From Table 2 and Table 3, we can see that the maximum values of vertical displacement and tensile stress on the bottom of the concrete slab would gradually decrease when the vehicle speed increased. If the vehicle speed increased from 30 to 120km/h, the maximum value of the vertical displacement of the concrete pavement would reduce approximately 70%, and the tensile stress on bottom would reduce approximately 50%. Speed has a significant effect on stress and strain properties of the concrete pavement structure.

Validation of the Model

To validate the finite element model, the deflection and tensile stress on the bottom of the concrete slab are calculated by the Westergard formula when the load is right on the center of the slab, and compare with the one calculated by the finite element model when the speed is 0. The compared results are shown in Table 4.

Table 4 . The Results Comparing of Different Calculation Methods

Calculation Methods	Westergard Formula	FEM	Relative Error
Deflection (mm)	0.681	0.702	3.1%
Tensile Stress on the Concrete Slab Bottom (MPa)	1.245	1.268	1.8%

Table 4 indicates that the relative error of the deflection and the tensile stress which are computed by finite element method and the Westergard formula is very small. It proves the feasibility of the stress and strain computation by finite-element model developed in the ANSYS platform in this paper.

CONCLUSIONS

Through a finite-element model developed in the ANSYS platform, the stress-strain properties of concrete pavement under dynamic loads were studied. The main conclusions obtained are summarized below.

(1) The dynamic response of the concrete pavement structure under moving load not only has relationship with the natural vibration frequency, but also to the vehicle speed.

(2) The maximum values of vertical displacement and tensile stress on the bottom of concrete slab will gradually decrease when the vehicle speed increases.

(3) Speed has a significant effect on stress-strain properties of the concrete pavement structure. The dynamic properties should be considered in the concrete pavement design.

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Experimentation Study of the Failure Behavior of Concrete Plates Under Different Support Conditions

Lou Xiaoyu[1], Fu Hongyuan[1], Kong Xiangxing [2]

[1]School of Civil Engineering and Architecture, Changsha University of Science &Technology, Changsha, Hunan, 410076, China.

[2]The first Exploration and Design Institute of Communications Ministry of China, Xi'an, Shanxi, 710068, China Email: fuhy1@163.com

ABSTRACT: As presented and discussed in this paper, a series of experiments were conducted on cement concrete plates to study the fracture mechanism and failure behavior of cement concrete pavements. Various boundary conditions including a simple support, hinged support at both ends, and one fixed end only were considered. Accordingly, the fracture response and behavioral characteristics of the cement concrete pavement under these different support conditions were comparatively evaluated and the findings are discussed in this paper. From the study results, the corresponding linear fit-functions between the vertical displacements and the rupture loads under different support conditions were formulated.

INTRODUCTION

One of the primary causes of cement concrete pavement (CCP) failures in China is traffic overloading, predominantly in terms of the axle weights. Common failure distresses related to traffic overloading include pavement settlement, rutting, cracking, and even rupture. Redress of these distresses is often very costly, creating a financial burden on the already over-stretched tax-payers' money.

Most often, the rupture loads and failure mode of CCP structures are related to the support conditions of the cement concrete (CC) plates (Vos, 1985). When subjected to heavy traffic loading, dislodging, cracking, and fracture are the common form of distresses occurring around the corners and/or sides of the CC plates. To ensure structural integrity and satisfactory performance, a critical analysis of the boundary conditions and fracture response behavior of the CCP structure is imperative during the design stage (Tang, 2003).

In this study, a series of laboratory experiments were conducted on CCP plates to characterize the fracture mechanism and failure behavior of CCPs when subjected to static incremental-loading. Results of these experiments, including the deformation and fracture response of a simulated CCP structure under different support conditions, are presented and discussed in this paper.