2020 International Conference on Computer, Network, Communication and Information Systems (CNCI 2020)

Responses of Cement Concrete Pavement with Initial Cracks Under Variable Amplitude Impact Loadings

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Keywords: Impact load; cement concrete pavement; XFEM; crack; settlement.

Abstract: The impact loading has a significant effect on the failure of the cement concrete pavement with the initial cracks. In this paper, the numerical simulation method is used to explore the dynamic response of cement concrete pavement with different initial crack lengths under variable amplitude impact loadings. It is found that the length of crack propagation increases rapidly with the increase of load amplitude. However, the increase rate will slow down as the load amplitude increases to a certain amount. The settlement mainly occurs in the loess layer. With the increase of the load amplitude, the settlement at the loading center point will increase, and the time of occurrence will also lag behind the time of the peak load. The deformation of the loess layer changes from elastic compression to elastic-plastic compression. When the initial crack length is small relative to the thickness of the surface layer, it has a significant effect on crack propagation and settlement. And with the increase of the load amount, the influence of the initial crack length on the settlement increases in turn.

1. Introduction

Cement concrete pavement is widely used in China, which is common in airport pavements and highways. Under special circumstances such as emergency landing and shell launch, the pavement structure will experience impact loadings. For cement concrete pavements with initial cracks, the pavement crack propagation and settlement curves are closely related to the form of impact loadings. And the impact loading amplitude is the most noteworthy form of the parameter. Therefore, it is significant to study the impact loading amplitude on the cement concrete pavement with initial cracks.

Dong et al. [1] have shown that the extended finite element method (XFEM) is an effective tool to study concrete cracking and crack propagation. Xie et al. [2] described the principle of XFEM and the influencing factors of each parameter in detail. It is found that XFEM can achieve high precision and accuracy under coarse mesh conditions through three simulation analysis examples. Hao Wang et al. [3] simulated the Falling Weight Deflectometer (FWD) and moving vehicle loading by XFEM. The results show that the FWD load can cause greater road surface response when the asphalt layer thickness decreases or the temperature increases. Ru et al. [4] calculated the type I crack by XFEM, and pointed out that the finite element mesh is independent of the crack surface, which is no need to encrypt the mesh at the crack tip. Xiao et al. [5] studied the response characteristics of various concrete pavements under FWD load by field tests. The results show that the settlement of the pavement increases with the increase of the load, and the growth rate increases first and then decreases.

At present, the research on cracks of cement concrete pavement under impact load is not systematic, and the application of XFEM to dynamic crack propagation has not been widely carried out. Therefore, this paper focuses on the influence of impact loading amplitude on the cement pavement with the initial cracks. A series of numerical simulations for the cement concrete pavement with different initial crack lengths has been conducted.

2. Road Numerical Model

Numerical simulations were performed using XFEM. Tong et al. [6] determined the reasonable and reliable parameters by comparing the numerical simulation results with two classical tests. Therefore, this pape0r continues to use these parameters to analyze the influence of impact loading on cement pavement with initial cracks.

Due to the symmetry of the pavement structure and impact loading, the numerical simulation uses a 2D model. The road model and mesh are shown in Figure 1. The road structure layer is composed of surface course cement concrete, base course lime soil and soil course loess with their thickness of 180mm, 180mm and 3000mm respectively. In this model, the two sides constrain the lateral (x-direction) displacement, and the bottom edge constrains the displacement in both the lateral and vertical directions (x and y directions). The surface cement concrete slab adopts the extended finite element based cohesive crack model, the base lime soil adopts the Mohr-Coulomb model and the loess adopts the DP model. Table 1 shows the main numerical simulation parameters for each structural layer.

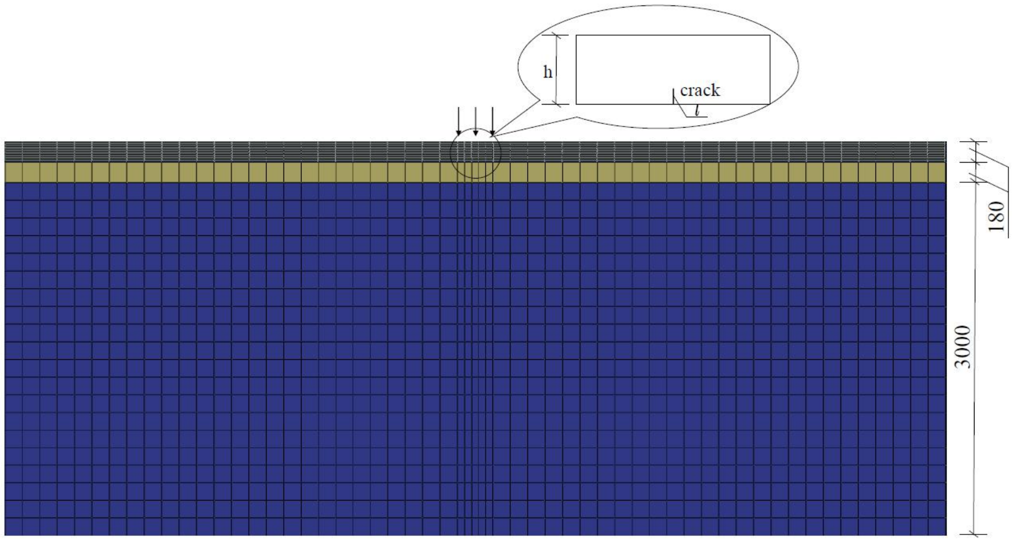


Figure 1: Road numerical model and mesh division (unit: mm).

Table 1: Parameters for pavement structure.

Material	Elastic Modulus/ MPa	Density /kg•m^{-3}	Poisso nratio	The angle of internal friction / °	Cohesion /kPa	Tensile strength f_t/MPa	Fracture energy $G_f/N/m$
Cement concrete	30000	2500	0.3	/	/	3.33	124
Calcareous soil	700	1750	0.35	32	90	/	/
Loess	100	1800	0.3	22	56	/	/

As shown in Figure 1, the initial crack is set at the center position below the surface course, and the ratio l/h of the initial crack length and surface course thickness is set to 1/18, 1/9, 1/6 and 2/9. The impact load area is a circle having a radius of 0.15 m from the center of the surface layer. The time history curve of the impact load is shown in Figure 2, and total action time is 34ms. The peak values P are 0.7 MPa, 1.05 MPa, 1.4 MPa, 2.1 MPa, and 2.8 MPa, which are obtained by adjusting the standard FWD load (P = 0.7 MPa) multiples.

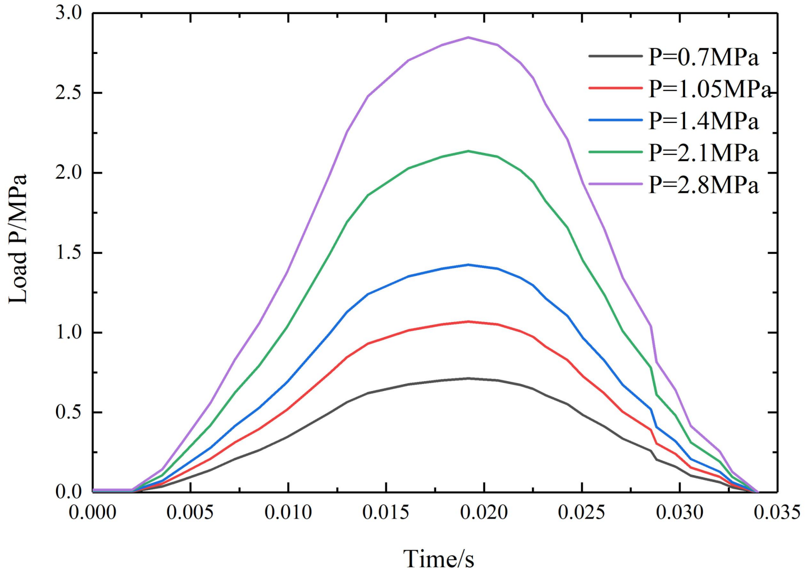


Figure 2: Time history curve of impact loading.

This paper focuses on the influence of impact loading amplitude on crack propagation and compares the analysis under different initial crack lengths. Therefore, 20 sets of numerical simulations were carried out by changing the loading amplitude and initial crack length.

3. Calculation Results and Discussion

3.1. Influence of loading Amplitude on Crack Propagation

Figure 3 shows the final crack propagation length under different impact load peaks P when l/h is 1/18. When the load peak P is only 0.35 MPa, the final crack propagation length is only 60 mm. With the increase of P, the crack propagation length increases significantly. When P is 2.8 MPa, the crack propagation length reaches 110 mm. Figure 4 shows the final crack length as a function of load. In the process of increasing the load from small, the crack length increases rapidly in the initial stage. It is reflected that the impact load magnitude will directly determine the extent of crack propagation, and ultimately determine the pavement damage. After that, as the loading amplitude continues to increase, the crack length grows slower and tends to a fixed value. It is reflected that crack propagation is also restricted by many other factors.

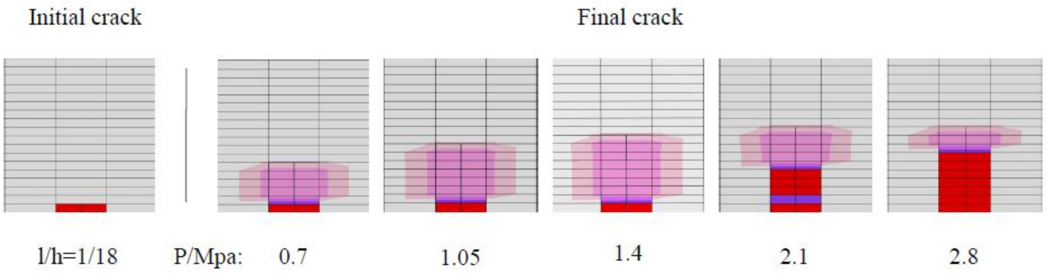


Figure 3: Final crack produced with different load peak (*l/h*=1/18).

Figure 5 shows the curve of 0.035s expansion with time before l/h is 1/18, where the dotted line is the load-time curve. It can be seen from Figure 5 that the crack propagation has a high consistency with the magnitude of the load. Under different peak loads P, the cracks begin to expand when the load reaches 0.5 MPa, and increase with the increase of the load. When P<=2.1MPa, the crack propagation length and the load effect reach the maximum at 0.02s. As the P is further increased to 2.8 MPa, the final crack length is equal to P=2.1 MPa, but the appearance time is advanced to about 0.16s.

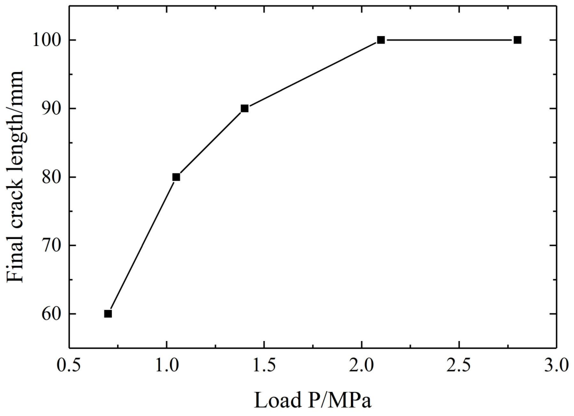


Figure 4: Final crack length with load peak curve (l/h=1/18).

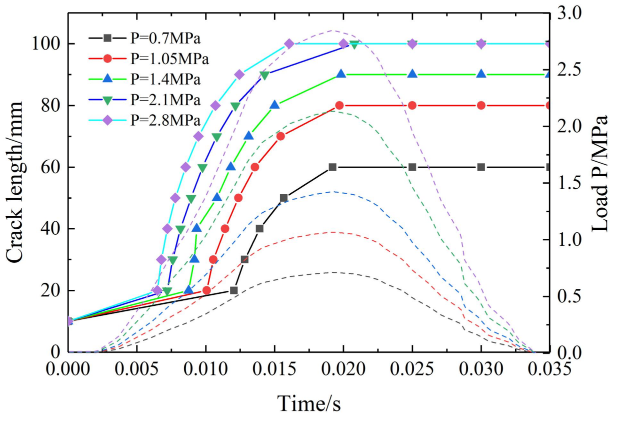


Figure 5:Crack length-time history curve of the first 0.035s.

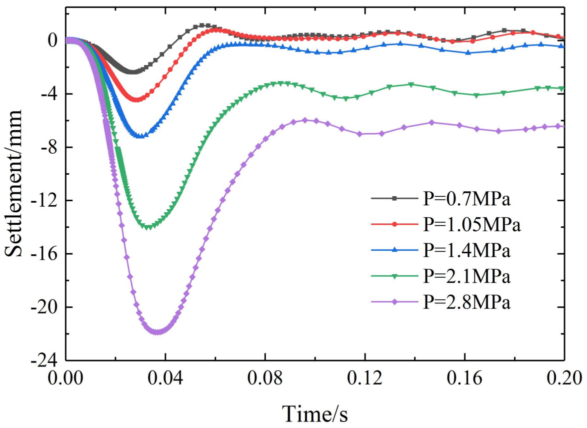


Figure 6: Settlement-time curve at central point of the loading area.

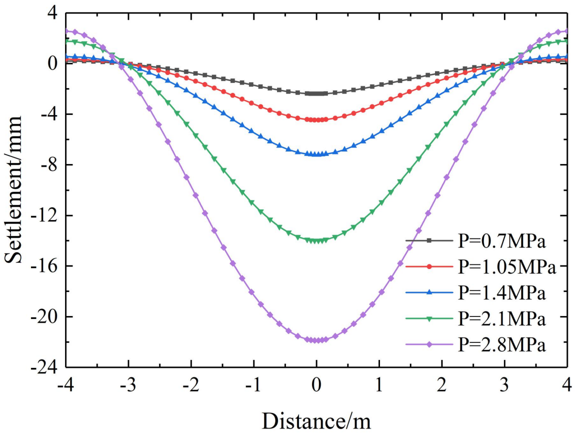


Figure 7: Deflection basin when maximum settlement happens.

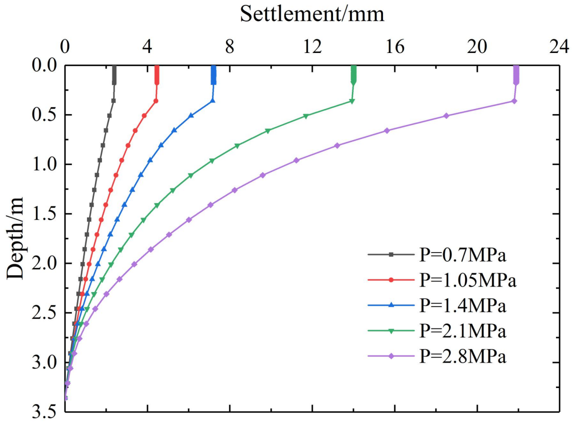


Figure 8: Settlement-depth curve of center point of the loading area when maximum settlement happens.

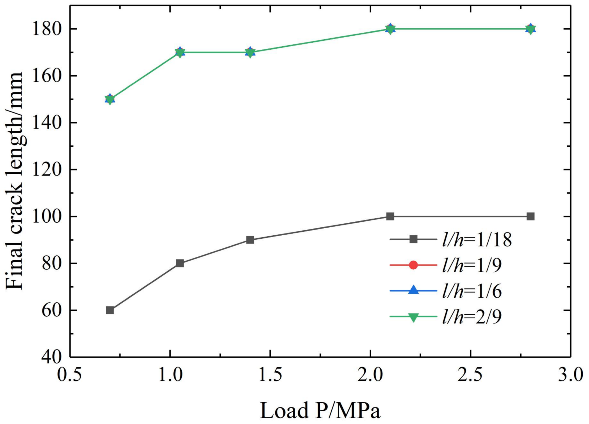


Figure 9: Final crack length with load peak curve (l/h=1/18, 1/6, 2/9).

Settlement-time curve at central point of the loading area is shown in Figure 6. The settlement at the loading center point is similar to the impact load curve, which quickly reaches the peak and then rebounds to a stable value. However, the time to reach the peak of the settlement is later than the time to reach the peak value of the impact load and the maximum length of the crack extension. Moreover, as the peak value of the load increases, the peak value of the road surface settlement increases, and the lag time of the peak value of the settlement increases.

Figure 7 shows the deflection basin when the maximum settlement happens. As the distance from the loading center point increases, the settlement of the road surface decreases. The settlement decreases to zero at a position about 3.15 m from the center point, and then gradually rises above the road surface. As the peak load P gradually increases, the settlement at the center of the loading increases, and the height of the upward bulge on both sides increases.

The settlement-depth curve of center point of the loading area is shown in Figure 8. It can be seen from Figure 8 that the settlement mainly occurs in the loess layer (ie, 0.36 m or less from the road surface), and the base course lime soil also contributes a small amount of settlement deformation. When P is 0.7MPa, the sedimentation amount shows a linear relationship with depth in a certain depth range, indicating that the loess layer mainly occurs elastic compression. However, as the peak load P increases, plastic compression occurs. When P is increased to 2.8 MPa, the whole curve shows a nonlinear relationship. At this time, the loess layer is mainly plastically compressed.

3.2 Comparative Analysis of Different Initial Crack Lengths

Figure 10 shows the final crack propagation length under different impact load peaks P when l/h is 1/9, 1/6, 2/9. When l/h is 1/9, 1/6, and 2/9, the crack propagation results are completely consistent. It indicates that the initial crack length has little effect on the crack propagation when the initial crack length is larger than the thickness of the surface course. Figure 9 shows the final crack length with load peak curve (l/h=1/18,1/6,2/9). Compared with l/h of 1/18, l/h has a large increase in the final crack propagation length at 1/9, 2/9, and 1/6. It indicates that the initial crack length has a great effect on the crack propagation when the initial crack length is small relative to the thickness of the surface course.

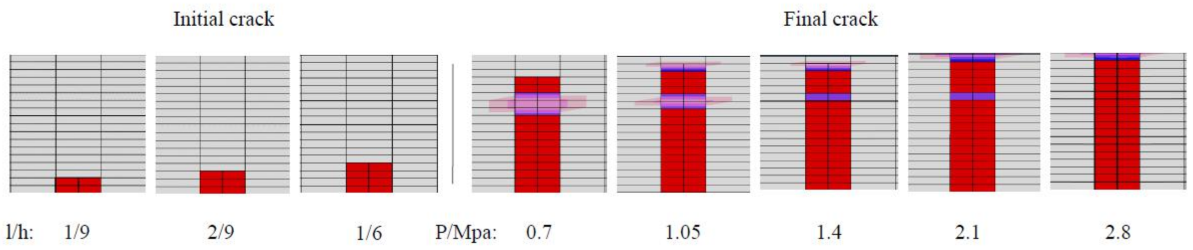
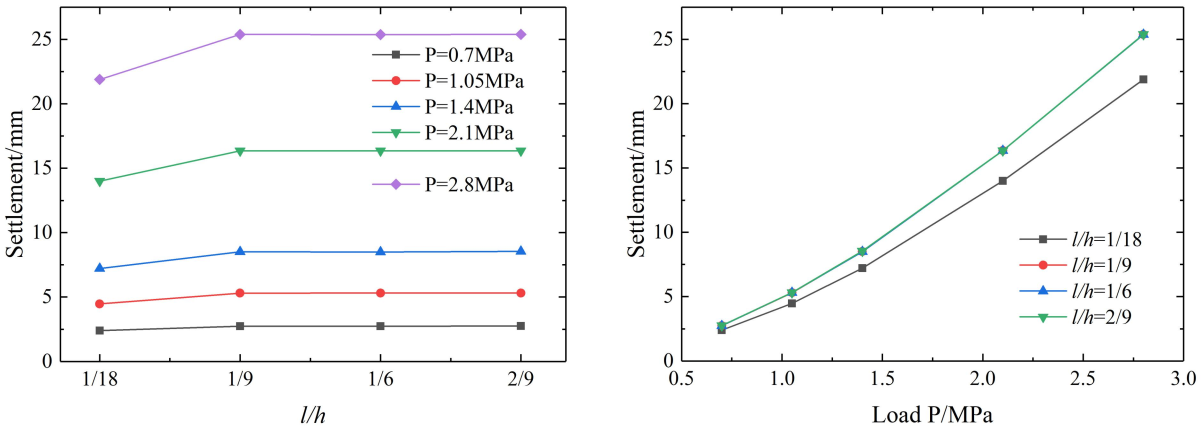


Figure 10: Final crack produced with different load peak (l/h=1/9, 2/9, 1/6).



(a) (b)

Figure 11: Settlement curve of center point of the loading area when maximum settlement happens.

Figure 11 (a) and (b) show the curve of the settlement of the center point at the peak time with the initial crack length and the curve of the settlement with the load value. It can be seen from Figure 11 (a) that, similar to the crack propagation, the initial crack length has a large influence on the settlement when the thickness of the initial crack is small relative to the thickness of the surface layer. When the initial crack length is larger than the thickness of the surface layer, the initial crack length has little effect on the settlement. In addition, as shown in Figure 11 (b), the settlement curve with load peak is nonlinear. The reason is that the initial crack has a great influence on the settlement of the pavement structure. With the continuous expansion of the crack, the slight fracture zone formed by the pavement structure around the crack further reduces the ability of the pavement to withstand the impact load, which directly leads to the road surface settlement increasing continuously. Under the dual effects of increased load and crack propagation, the increase in settlement will be faster.

In order to study the depth of influence of the initial crack on settlement, Figure 12 shows the settlement-depth curve of center point of the loading area when maximum settlement happens (P=0.7MPa). The initial crack length has an effect on the settlement within about 0.9 m from the top of the panel. However, when the distance is more than 0.9 m, the initial crack length has little effect on the settlement. Further quantitative indicators, we assume that the settlement difference is less than 0.1mm, 0.05mm is recognized as the initial crack length has no effect on the settlement. As shown in Figure 13, the impact load magnitude can have a large impact on the depth of influence. As the load magnitude increases, the depth increases in turn.

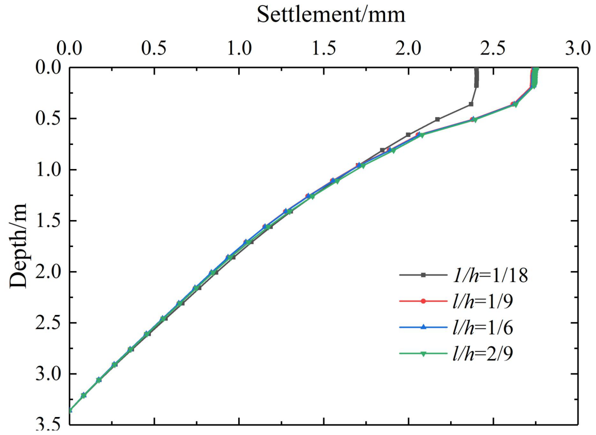


Figure 12: Settlement-depth curve of center point of the loading area when maximum settlement happens (P=0.7MPa).

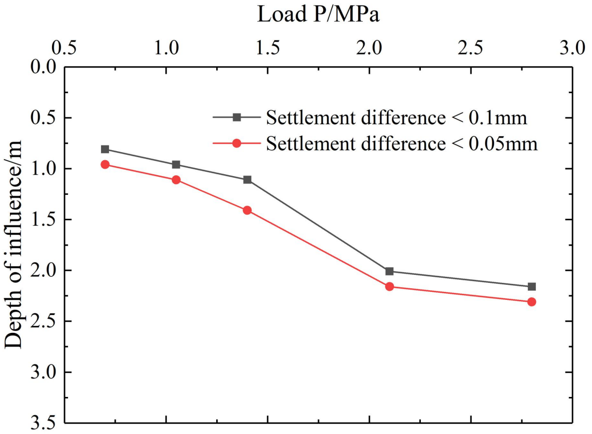


Figure 13: Initial crack influence depth variation curve with load value.

4. Conclusions

The purpose of this paper is to explore the dynamic response of cement concrete slabs with different initial crack lengths under different load magnitudes. The main conclusions obtained are:

1) The impact load acts on the cement concrete slab containing the initial crack, and the crack propagation and load action are highly consistent, which reflects the impact loading amplitude directly determines the degree of crack propagation; When the loading amplitude continues to increase, the crack length becomes slower with the load growth, which reflects the crack expansion and is also restricted by many other factors.

2) The cement pavement settlement is similar to the impact load curve. It quickly reaches the peak and then rebounds to a stable value. The sedimentation decreases along the loading center point to the two sides, and bulges occur on both sides of the road. The settlement mainly occurs in the loess layer. In addition, with the increase of the loading amplitude, the settlement peak gradually increases, and the time of occurrence also lags. The deformation of the loess layer changes from elastic compression to elastic plastic compression.

3) Under the action of different load magnitudes, the initial crack length has little effect on crack propagation and settlement when the initial crack length is larger than the thickness of the surface course; however, the effect is significant when the initial crack length is smaller than the thickness of the surface course. More than, as the load value increases, the depth of the initial crack length affects the settlement depth.

Acknowledgments

This work was financially supported by The National Natural Science Fund (11872092).

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