

Analysis of Contraction Joint Width Influence on Load Stress of Pavement Panels

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Abstract. The width of transverse contraction joint of the cement road varies with temperatures, which leads to changes in load transmission among plates of the road surface and affects load stress of the road plates. Three-dimensional element analysis software EverFE is used to address the relation between the contraction joint width and road surface load stress, revealing the impact of reducing contraction joint width. The results could be of critical value in maintaining road functions and extending the service life of cement road surfaces.

1. Foreword

Joint is one of the structural details for cement pavement. Load transmission and durability of the joint system directly affect the performance of the cement pavement. Compared with asphalt pavement, in the structural design of the cement pavement, research and design of the joint system are an important composition. Joint system are critical components in the structural design of cement pavement, drawing much more emphasis compared to asphalt pavement.

Heilongjiang Province is located in the northeastern end of China, with a maximum annual temperature difference between 77.6-84.0°C. Expansion and contraction of the cement pavement are severe, which leads to significant changes in the width of the contraction joints. Friction resistance of the joint sides could be greatly diminished, and load transmission of the contraction joints can deteriorate drastically. With inadequate load transmission of the contraction joint system, stress conditions of the pavement plates are greatly affected, reducing the bearing capacity, leading to structural damage of the pavement. In the process of amending the current “Specifications of Cement Concrete Pavement Design for Highway”, committee experts noted that load transmission ability of the contraction joint load transmission system must be improved to ensure the well-functioning and endurance of the cement pavement. Affected by many factors, although acknowledgment on importance of the joint load transmission system is deepened, the application and research are still in slow progress; The realization of such requirements, however, has been met with a variety of setbacks despite growing attention towards the importance of the topic.

Climate conditions in Heilongjiang Province are severe, and it is necessary to reinforce the “contraction joint load transmission system”. Harsh climate conditions in Heilongjiang Province further necessitates the emphasis on the load transmission system of contraction joints. Since 2006, China has started a new research campaign on cement pavement, where structural durability the working conditions of the cement pavement have raised great attention. Research of the contraction



joint load transmission system of the pavement plate is of great significance for correctly acknowledging and assessing the structural durability and working conditions of the pavement plates, and analysis on the effects of the contraction joint width would be one of the cornerstones for optimizing the load transmission system of the contraction joints.

2. On-site observation and measurement of contraction joint width changes

A series of tracking observation and measurements have been carried out at K524+300 on the highway from Harbin to Daqing. The highway sector is under cold-to-temperate continental monsoon climate, with an annual temperature average of 4.8°C, a recorded temperature maximum of 37.6°C and minimum at -39°C, with a frostless period averaging 140 days and an annual precipitation average of 443mm, which is focused through July, August, and September. Maximum frozen penetration is at 2.07m and maximum snow thickness at 15cm. See Table 1 for results from observations and measurements (a side measurement point, No.2, was loosened by snow removal, voiding the two entries). Observations and measurements indicate that the contraction joint width varies significantly with seasons, with maximum contraction joint width of 3.5mm.

Table 1. Testing results of the contraction joint width

Testing point Testing time	Changes of the contraction joint width(cm)		
	No 1	No 2	No 3
December 3	11.57	13.88	9.90
May 21	11.42	13.95	9.72
September 25	11.26	—	9.62
November 28	11.49	13.76	9.94
May 20	11.40	13.45	9.72
June 13	11.40	13.48	9.88
September 29	11.41	13.39	9.79
February 27	11.59	13.91	9.97
Maximum value(mm)	3.3	—	3.5

3. Influence of contraction width changes on the load stress in pavement plates

To analyze influence of contraction joint width on the load stress of the pavement plates, we employed the EverFE, a specialized software for the 3D Finite Element (FE) analysis of JPCP, jointly developed by Washington University and Maine University of the United States of America. This program is capable of simulating the mechanical responses under various wheel loads and with temperature functions of jointed cement concrete pavement (JPCP), and calculates the mechanical responses of up to 9 pavement plates in a 3 by 3 matrix, and up to 3 base layers with joint load transmission system under various temperatures and loads. To simplify the calculations, we employed a model involving 4 pavement plates in a 2 by 2 layout (Figure 1). Plane size of the pavements is 4.5m by 5.0m across and 26cm thick. 100kN load from double wheels on single shafts is added onto the exact middle of one side of the transverse joint plates, as indicated in Figure 1. The base layer consists of 20cm of grit stabilized by 6% cement. The bottom layer consists of 20cm of sand-gravel stabilized with 5% cement. The foundation response modulus is set to $K=0.027\text{MPa/mm}$ under the linear force-deflection assumption of Winkler's model. Diameters of the dowel bars and tie bolts are set to 32mm and 16mm, respectively, and loosening of the dowel bars is set to 0.01mm.

The maximum load stresses of the pavement plates under different contraction joint widths are listed in Table 2. Figure 2 shows the tensile stress distribution as well as that of the bending deformation.

Figure 3 illustrates the relation between the maximum tensile stress and the contraction joint width in the bottom layer of the plates. Upon providing dowel bars is for the contraction joints, the maximum tensile stress in the plate bottom becomes less affected by the width of the contraction joints. By

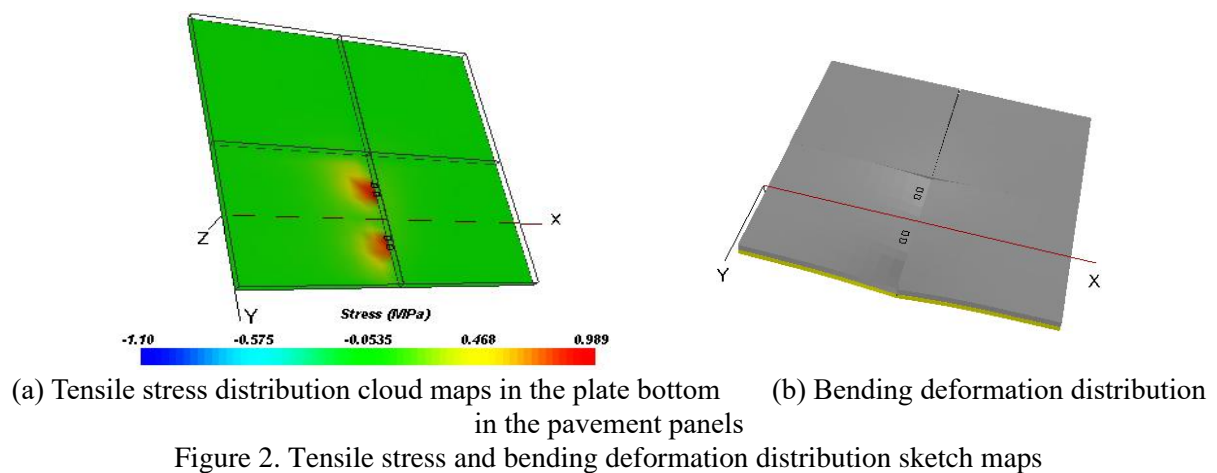
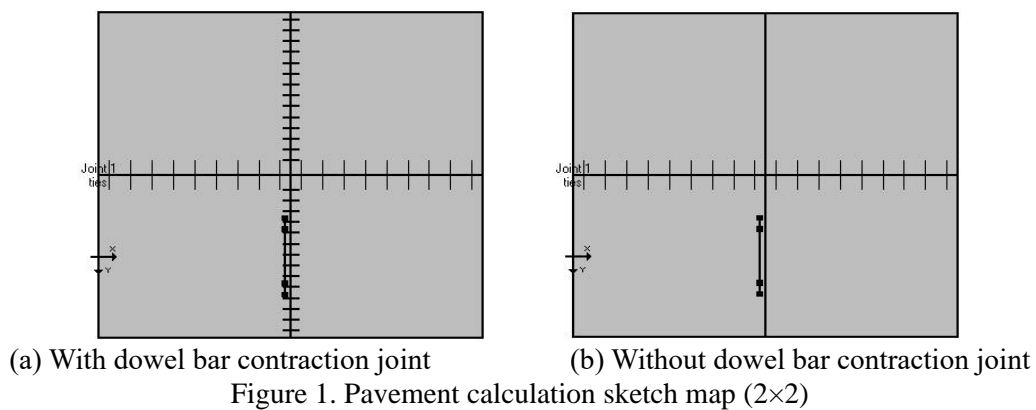


Table 2. Stress calculation results for cement concrete pavement panels under different contraction joint widths, in MPa

Contraction joint load transmission system						
No.	Contraction joint width (mm)	Pre-cut contraction joints with dowel bars		Pre-cut contraction joints without dowel bar		The plate under the maximum stress
		Maximum compressive stress	Maximum tensile stress	Maximum compressive stress	Maximum tensile stress	
1	0.1	0.782	0.693	0.783	0.693	The plate under direct load
2	0.2	0.811	0.723	0.811	0.724	
3	0.4	0.919	0.819	0.925	0.824	
4	0.6	0.965	0.862	0.975	0.871	
5	0.8	1.005	0.901	1.028	0.923	
6	1.0	1.027	0.922	1.038	0.952	
7	1.5	1.039	0.933	1.087	0.979	
8	2.0	1.039	0.934	1.096	0.989	
9	2.5	1.039	0.934	1.098	0.991	
10	3.0	1.039	0.934	1.098	0.991	

contrast, tensile stress in the plate bottom without dowel bar contraction joints is significantly more prone to be affected by the increasing of contraction joint width. Moreover, after the pre-cut contraction joints are cracked, there is a stage for rapid increasing of maximum tensile stress in the plate bottom as the joint width increases, which indicates a rapid deterioration of the mechanical integrity of the pavement.

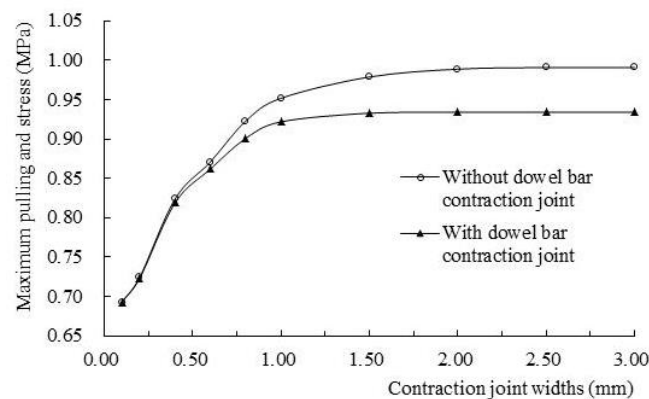


Figure 3. Relation of maximum pulling and stress at the plate bottom and contraction joint width

Based on experiences from European countries and the United States, the World Road Association (PIARC) proposed the recommended scope of applications for contraction joints without dowel bar: for frozen wet sections, with a base layer stabilized by cement or pitch, the capacity for cargo transportation (assuming an axial load of 13t) should be restricted to no more than 150 vehicles/day, or alternatively, for cargo vehicles with axial load of 9-10t, no more than 300 vehicles/day). In the case of an erosion-resistant top for the base layer, this capacity threshold could be improved by 1-2 times. Given that the pavement structure is designed with drainage, this capacity could be further improve by 1-2 times. Recent domestic researches indicate that, for cement pavements, the design of the joint load transmission system plays a critical role, in the sense that: (1) joints often act as the weakest link in the cement pavement, whose cracking was greatly contributed by the occurrence of plate deflection adjacent to the joint, as well as excessive warping due to temperature stress; (2) the local climate in Heilongjiang Province involves a large annual temperature difference, which further compounds the problem of pavement expansion and contraction. Sheer dependence on the friction and mechanical integrity of embedding aggregated fillings on the sides of the transverse pre-cut contraction joints would often prove insufficient and unreliable over time. The downgraded transmission capacity would often lead to excessive loading stress and warping in the panels; (3) the increased warping on the sides and corners of panel plates lead to amplified erosion of the semi-rigid base layer top, as a result of the phenomenon as free water being pumped into jet streams beneath the panels when loads are periodically applied; (4) the resulting faulting and misaligning of panels along the joints which, despite being minor in the early stages, poses a much-worsened driving comfortability; (5) applying dowel bars to the joints acts as an important measure for avoiding the joint “bumping” annoyance on common cement concrete pavements, which also helps greatly in maintaining pavement flatness in the long term. Therefore, in the process of amending the current design specifications, committee experts pointed out that “setting dowel bars for transverse contraction joints is the most feasible and cost-effective measure for improving stress conditions of the base layer and pavement plates, as well as ensuring the performance and service life of the pavements. Such conclusion is backed up by the oversea experience over dozens of years”, and such vital functions could not be simply replaced by increasing the thickness of the plates.

Given an annual temperature difference between 77.6-84.0°C in the Heilongjiang Province, the cement concrete pavements have long been troubled by the expansion and contraction around the year, and therefore, the employment of reinforcing measures for the load transmission system at the contraction joints and between plates becomes a need which is increasingly pressing.

4. Conclusion

From a cement production point of view, Chinese domestic cement production has been ranked the 1st throughout the past 20 years with huge exporting quantities. In Heilongjiang Province alone, the cement production capacity would be capped at 40 million tons/year in accordance with the mandate from the provincial “Eleventh Five-Year Plan for Cement Industry”. The production capacity was registered at 35 million tons in 2016, with sufficient supply, relatively stable and ever improving quality.

The cement pavement, as one of the main types of road paving, effectively utilizes the abundant local cement resources. The construction of durable and well-functioning cement pavements would be of great significance for the sustained economic growth and traffic improvements.

However, local cement pavements in Heilongjiang Province, across all road levels, are often found suffering prematurely, repeatedly and persistently from structural damages. This not only brings forth significant deteriorations in terms of road performance and service life, but also inflicts serious maintenance issues. Such technical constraints greatly restricted the development and application of cement concrete pavements.

It is evident that the structural features of the cement pavement incorporate numerous joints from a mechanical perspective, and such joints would pose a potential weak spot for the pavement integrity. This becomes especially true when the loads are applied onto the contraction joint edge, or the corner of the panels, as elevated stress concentration would often lead to the cavitation beneath the panel, as well as structural damage to the panels themselves. Therefore, reinforcing the contraction joint system is an effective approach for ensuring the bearing capacity of cement concrete pavement, reducing structural damages and improving the durability.

In terms of computational assumptions, our study considers the effect of the loosening of dowel bars, although the cavitation beneath the panels or the deterioration of base layer and road bed are yet to be addressed. Assuming the latter two factors, we expect an even stronger correlation between the tensile stress in the plate bottom and the contraction joint width, without applying dowel bars. According to our observations and measurements on the local Suiman Highway, between the cement concrete pavements with or without dowel bars, the rebounding warping observed are 0-5 (*0.01mm) and 0-7 (*0.01mm), respectively, after 2 years into service, averaging a difference around 33%. After the other half of the road has been opened to traffic for 9 years without dowel bars, pavement rebounding warping registered 5-44 (*0.01mm), with some points registering over 90. Pavement bearing capacity has been significantly downgraded, and structural damage has been widespread. In conclusion, under the local climate conditions of Heilongjiang Province, where freezing-thawing cycles are frequent, uneven thermal expansion and contraction in the concrete base are rather severe, and the ensuing joint width variations could largely hinder the bearing capacity of cement pavements, the minimization of the adverse effects from contraction width changes is of vital significance for reducing structural damage, improving road performance as well as extending the service life.

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