The Challenges of the Accelerated Testing of Jointed Concrete Pavements

Angel Mateos[2](✉), Rongzong Wu[1], John Harvey[1], Julio Paniagua[1], Fabian Paniagua[1], and Robel Ayalew[1]

[1] Pavement Research Center, University of California, Davis, USA
[2] Pavement Research Center, University of California, Berkeley, USA
angel-mateos@berkeley.edu

Abstract. One of the main challenges of the accelerated pavement testing (APT) is reproducing the distress mechanisms that will cause the structural failure of the pavement in the field. This challenge is particularly difficult for jointed concrete pavements since some of their main distresses are driven by critical combinations of concrete hygrothermal conditions, slab's support, and traffic loading that are very difficult to reproduce during the accelerated testing. Two such distresses are top-down cracking, either transverse or longitudinal, which is driven by simultaneous loading at distant locations, and faulting, which is driven by fines pumping produced by wheels moving at relatively high speed. Furthermore, while traffic loading is the main action that can be relatively easily controlled in the accelerated pavement testing, temperature and moisture-related shrinkage actions, just by themselves or in combination with traffic loading, result in slabs deformations and concrete tensile stresses that cannot be ignored. This paper presents a discussion of these and other limitations of the accelerated testing of jointed concrete pavements. The discussion is supported by modeling results and by experimental data collected during the testing of concrete pavements with the Heavy Vehicle Simulator in California.

Keywords: Jointed plain concrete pavement · Temperature gradients · Drying shrinkage · Top-down cracking · Faulting · Ambient environment action

1 Introduction

The accelerated pavement testing (APT) can be defined as the controlled application of wheel loading to pavement structures for the purpose of simulating the effects of long-term in service loading conditions in a compressed time period (Hugo and Martin 2004). This is done while environmental effects on the pavement are typically controlled and measured (Steyn 2012). The goal of the simulation of the long-term in service loading conditions is to reproduce the distress mechanisms that will cause the structural failure of the pavement in the field. This is why, for example, the evaluation of the rutting performance of asphalt materials is typically conducted at high temperatures (Wu et al. 2008), the evaluation of subgrade rutting performance is typically conducted with a near-surface water table (Mateos and Soares 2014), the simulation of bottom-up asphalt fatigue cracking typically requires testing of thin flexible pavements

A. Chabot et al. (Eds.): *Accelerated Pavement Testing to Transport Infrastructure Innovation*, LNCE 96, pp. 178–185, 2020.
https://doi.org/10.1007/978-3-030-55236-7_19

(Mateos et al. 2011), etc. Similar challenge is applicable to the APT of jointed concrete pavements.

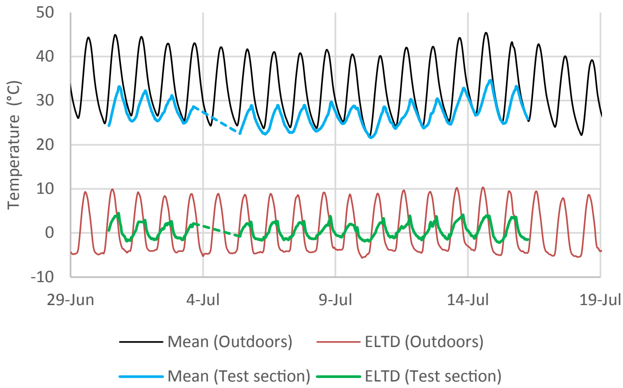
The main structural distresses that the jointed concrete pavements undergo in the field are cracking and faulting (AASHTO 2015). The loss of longitudinal smoothness can be mainly regarded a consequence of these two main distresses. Truck axle configuration plays a major role in top-down cracking while truck speed plays a major role in faulting (NCHRP 2004). Nonetheless, most APT facilities cannot reproduce realistic truck axle configuration and speed. Furthermore, while concrete hygrothermal conditions play a major role in both cracking and faulting (NCHRP 2004), the simulation of these conditions in the APT is not a trivial task. This paper explores how the limitations of most APT devices/facilities impact the evaluation of jointed concrete pavements.

Scope. This paper is focused on accelerated pavement testing devices, either linear or circular, typically known as test tracks. The Heavy Vehicle simulator (HVS), the Ifsttar carrousel, and the Australian Accelerated Loading Facility are examples of these devices. The accelerated testing of jointed concrete pavements in test roads like NCAT or MnROAD present very different challenges that are not discussed in this paper.

2 Identification of Limitations of the APT of Jointed Concrete Pavements

2.1 Simulation of Thermal Actions

Except during the early age of concrete, when the heat released by the cement hydration process is considerable, the temperature of the slab is determined by the heat exchange between the slab and the ambient environment. The energy from the sun radiation plays a major role on this exchange. Obviously, the impact from the sun radiation does not exist when the APT testing is conducted indoors. Even when the testing is conducted outdoors, most APT devices are large enough to cover most of the section being tested. This shedding may result in undesirable differential heating of the slabs, which may considerably distorts the outcome of the test. In an APT experiment that was recently concluded at the University of California Pavement Research Center (Mateos et al. 2019), the top, south, east, and west panels of the Heavy Vehicle simulator (HVS) environmental chamber were installed to prevent the differential heating of the slabs (Fig. 1). The north panels were left open since no sun radiation could come in from that side. While the opening allowed air temperature on the tested section to change as the outdoors temperature, the lack of sun radiation resulted in a much smaller variation of the slab mean temperature and the equivalent linear temperature difference (ELTD), compared to the sections that were not affected by the shed of the HVS (outdoors series in Fig. 1).



a)

b)

Fig. 1. a) Comparison of slab mean temperature and ELTD between uncovered concrete section (Outdoors series) and section under the HVS shed (Test section series), b) tested section, environmental chamber is open on its north side

2.2 Simulation of Hygral Actions

Concrete drying shrinkage results in slab contraction and concave upwards curvature, similar to negative (top of the slab cooler than bottom) temperature gradients. For any particular concrete pavement, these effects considerably vary versus time, depending on concrete age and weather conditions, as shown on Fig. 2 example. This figure includes the differential drying shrinkage (top versus bottom of the slab) in a set of concrete slabs built with different concrete mixes (Mateos et al. 2019). Because the APT experiments are typically conducted in a relatively short time period, in the order of weeks, the outcome of the test may be highly dependent on the time of the year when it is conducted.

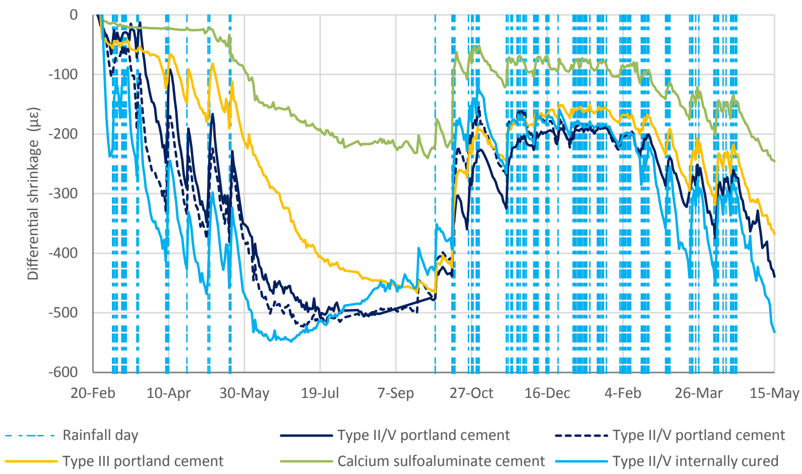


Fig. 2. Differential drying shrinkage (top versus bottom of the slab) in a series of concrete slabs built with different concrete mixtures; concrete slabs built on February 23–25

2.3 Transverse Joints Opening

The opening of the transverse joints is known to impact the load transfer efficiency (LTE) attributed to the aggregate interlock (NCHRP 2004). Among other factors, this opening is determined by the mean temperature of the slabs and the drying shrinkage. As explained in Sect. 2.1 and 2.2, the simulation of these two variables is not a trivial task. Furthermore, the opening of the transverse joints also depends on the thermal contraction that the concrete experiences after setting. This thermal contraction results in initial deployment of transverse joints at relatively large intervals, 10 to 45 m (ACPA 2002). Very frequently, the length of the APT sections is smaller than this interval and this may result in little opening of the transverse joints compared to the field, i.e., unrealistically high LTE.

2.4 Faulting of Transverse Joints

Transverse joint faulting is the result of the loss of support under the leave slab due to fines pumping from beneath the leave slab to beneath the approach slab. The pumping of the fines requires, in addition to an erodible base and free moisture under the joint, that the truck wheels travel at a relatively high speed. Unfortunately, the speed of the wheel is very low for most APT devices. Most linear devices, which are the most common worldwide, cannot reach 10 mph (Jones et al. 2012). Consequently, most APT devices cannot simulate transverse joint faulting. On the other hand, the loss of LTE due to the wearing of the aggregate interlock and the dowel-concrete interface can be adequately simulated in APT since this wearing is directly related to the stresses that develop under the wheel loading. An example of successful evaluation of the loss of LTE under accelerated loading is summarized in Fig. 3 (Mateos et al. 2019).

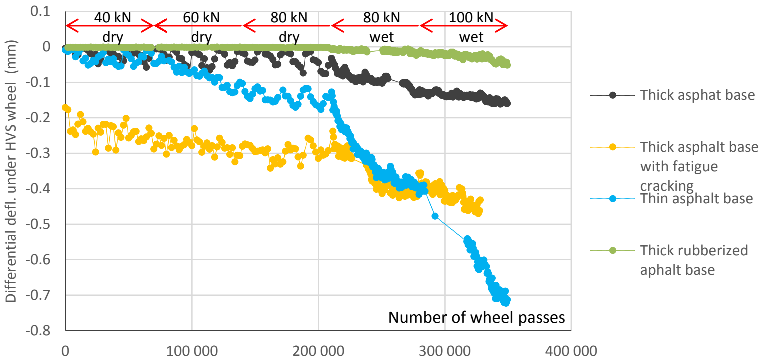


Fig. 3. Loss of LTE during HVS testing of thin bonded concrete overlay of asphalt, 6 × 6 slabs, undoweled

2.5 Top-Down Cracking

Top-down transverse cracking is the result of longitudinal tensile stresses that occurs at the top of the slab, at or close to the slab longitudinal edge, under certain loading conditions (NCHRP 2004). These loading conditions typically include the combined action of a truck steering and drive axles, each acting at one side of a slab, together with negative thermal gradient and drying shrinkage in the slab (Fig. 4). Similarly, longitudinal cracking is the result of transverse tensile stresses that occur at the top of the slab, close to the transverse joint, under certain loading conditions (Hiller and Roesler 2005). In this case, the loading conditions include, in addition to negative thermal gradient and drying shrinkage in the slab, the combined action of left and right wheels of the truck axle (Fig. 4). Unfortunately, to the best knowledge of the authors, only one APT device (at Kansas State university) uses a full axle (left and right wheels) and no APT device would be able to reproduce the combined action of steering and drive axles of the trucks. These facts, together with the limited simulation of thermal and drying shrinkage actions, result in limited capability of the APT to reproduce top-down cracking of jointed concrete pavements.

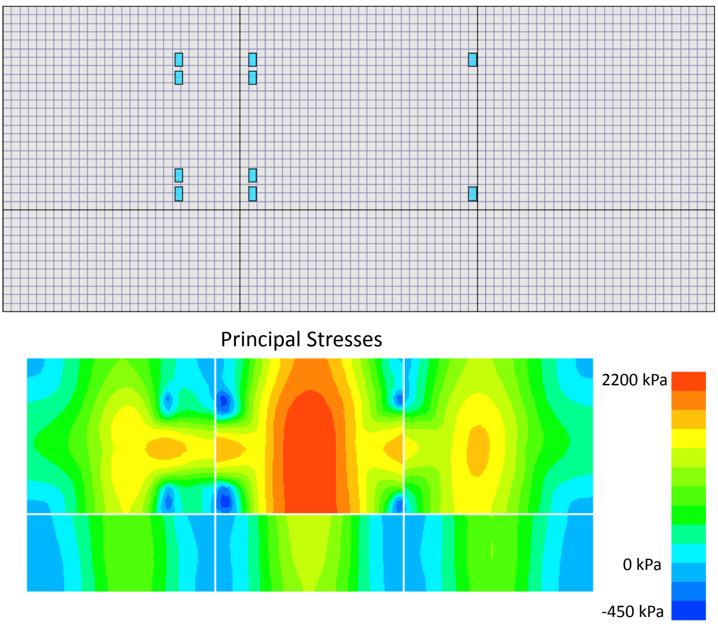


Fig. 4. Tensile stresses at the top of the slab that may result in longitudinal and transverse top-down cracking; loading includes the combined action of distant wheels and negative ELTD; truck loading is 80 kN (18000 lb) steering axle and 170 kN (40000 lb) drive axle; ELTD is −11 °C (−20 °F)

3 Discussion

Based on the limitations presented in Sect. 2, it is clear that reproducing certain distress mechanisms that may affect jointed concrete pavements poses a difficult challenge. Faulting is one of those mechanisms. As explained above, the onset of faulting requires pumping of the fines that cannot occur when the wheel speed is as low as it is in most APT devices. Fortunately, the loss of LTE can be adequately reproduced in APT. Modeling and field calibration seems to be the only option to extrapolate the loss of LTE in APT to loss of LTE and faulting in the field.

Reproducing top-down cracking represents a difficult challenge as well. In part because this type of cracking is highly sensitivity to the curvature of the slabs, either due to negative temperature gradients or drying shrinkage, or both, and in part because the combined action of distant wheels cannot be reproduced by the APT devices. In theory, it is possible to find combination of single wheel loading and slab’s negative curvature (concave upwards) that results in tensile stresses at the top and bottom of the slab that are close to the stresses that would occur under the join action of a real truck steering and drive axles (Fig. 5). Similarly to faulting, modeling would be the tool to make the extrapolation from the top-down cracking in the APT experiment (very likely corner cracking) to the top-down cracking in the field. In this case, the limited knowledge of concrete drying shrinkage in the field, concrete tensile creep, slab-base interaction, and other phenomena that play a role in top-down cracking would represent a major limitation in order to make the extrapolation. Furthermore, the simulation of the negative curvature of the slabs in the APT experiment would represent a practical challenge. At this moment, it does not seem like the APT community has fund a practical solution for such simulation. It must be indicated that increasing the load level is not the solution for simulating top-down cracking. If a negative curvature is not induced on the sabs, the increase in load level will likely trigger bottom-up cracking before top-down cracking takes place.

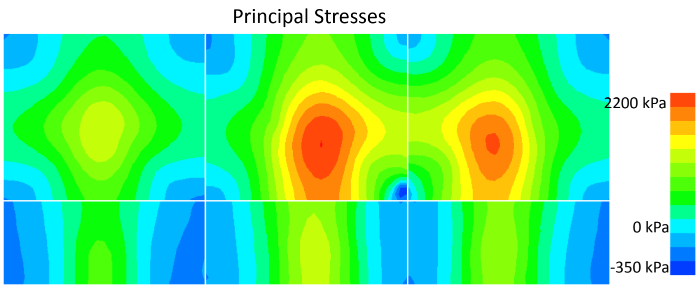


Fig. 5. Modeling of a single wheel loading (right wheel of the steering axle in Fig. 4); ELTD is −24 °C (−44 °F)

4 Conclusions

The simulation of faulting and top-down cracking in the accelerated testing of jointed concrete pavements presents a number of challenges, for three main reasons. The first one is the low wheel speed of most APT devices, which results in the inability to reproduce the fines pumping that the onset of faulting requires. The second reason is the half-axle loading of most APT devices, which results in limitations to simulate the combined action of distant wheels of the real trucks. The third reason is the practical difficulty of imposing the negative curvature on the slabs that, together with the combined action of distant wheels of the real trucks, trigger top-down cracking in the field.

Modeling is required to extrapolate APT results to faulting and top-down cracking the field.

The development of an approach to induce negative curvature in the slabs during the APT experiments remains a challenge for the APT community.

Acknowledgements. This paper describes research activities that were requested and sponsored by the California Department of Transportation (Caltrans). Caltrans sponsorship is gratefully acknowledged. The technical review by Caltrans, led by Deepak Maskey and Dulce Feldman from the Office of Concrete Pavement, and oversight by Joe Holland, of the Division of Research, Innovation and System Information, is appreciated.

Disclaimer. The contents of this paper reflect the views of the authors and do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This paper does not represent any standard or specification.

References

AASHTO: Mechanistic-empirical pavement design guide: A manual of practice. American Association of State Highway and Transportation Officials (2015)

ACPA: Early Cracking of Concrete Pavement—Causes and Repairs. American Concrete Pavement Association: IS405.01P (2002)

Hiller, J.E., Roesler, J.R.: Determination of critical concrete pavement fatigue damage locations using influence lines. J. Transp. Eng. **131**(8), 599–607 (2005)

Hugo, F., Martin, A.E.: Significant Findings from Full-Scale Accelerated Pavement Testing, vol. 325. Transportation Research Board (2004)

Jones, D., Harvey, J., Al-Qadi, I.L., Mateos, A. (eds.): Advances in Pavement Design Through Full-Scale Accelerated Pavement Testing. CRC Press (2012)

Mateos, A., Ayuso, J.P., Jáuregui, B.C.: Shift factors for asphalt fatigue from full-scale testing. Transp. Res. Rec. **2225**(1), 128–136 (2011)

Mateos, A., Soares, J.B.: Characterization of the stiffness of unbound materials for Pavement design: do we follow the right approach? J. Transp. Eng. **140**(4), 04014001 (2014)

Mateos, A., Harvey, J., Paniagua, F., Paniagua, J., Wu, R.: Accelerated testing of full-scale thin bonded concrete overlay of asphalt. Transp. Res. Rec. **2673**(2), 404–414 (2019)

NCHRP: AASHTO Mechanistic-Empirical Design Guide, NCHRP Project 1-37a. Transportation Research Board (2004)

Steyn, W.J.: Significant Findings from Full-Scale Accelerated Pavement Testing, vol. 433. Transportation Research Board (2012)

Wu, R., Harvey, J.T.: Evaluation of the effect of wander on rutting performance in HVS tests. In: Proceedings of the 3rd International Conference on Accelerated Pavement Testing, February 2008