DETERMINATION OF CRACKING STRESSES IN PAVEMENTS

INTRODUCTION

The HIPERPAV model uses a strength criterion to determine when a crack forms in a pavement. When the stress in the pavement (σ) is greater than the concrete strength (f_c)a crack is predicted to form.

$$\sigma\,(t) \geq f_c\,(t)$$

The time dependence has to be accounted for in the calculation of the stresses and the strength. Using the strain gage data, the time at first cracking is captured.

OBJECTIVE

Calculate the critical stress that induces early age cracking in the TX, AZ, NC, NE and MN pavements.

THEORY BEHIND CRITICAL STRESS DETERMINATION

A free body diagram of the loads acting on the pavement are shown in figure 1. Cracks were seen to form only at the sawed joints.

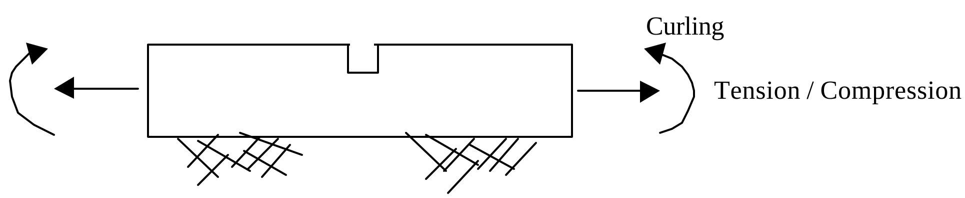

Figure 1. Free-body diagram of loads acting on the pavement.

The concrete pavement is subjected to both axial stresses (tension or compression) and curling stresses. Therefore, the critical stress at the top of the concrete pavement is a function of these two loads in addition to the contributions from drying shrinkage and concrete relaxation.

$$\sigma = \text{fcn}(\pm\sigma_{axial}, \pm\sigma_{curling}, \pm\sigma_{drying\ shrinkage} \text{ and } \pm\sigma_{relaxation})$$

Because these stresses are time dependent, they must be determined relative to each other. A typical plot of net strain and temperature vs. time is shown in figure 2.

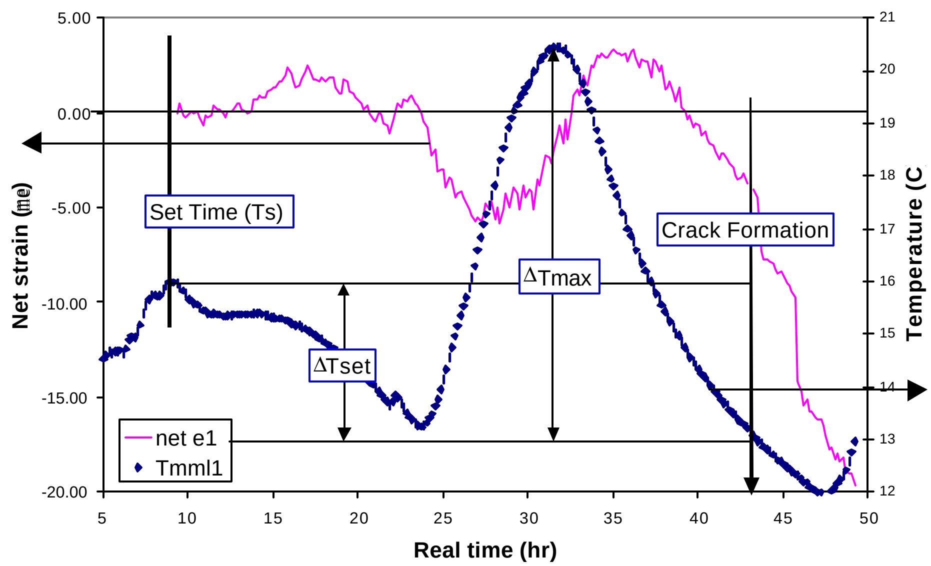

Figure 2. Plot of temperature and net strain vs. time for PCC pavement.

Prior to crack formation, the net strains recorded in the middle of the pavement are small (±5με). But after crack formation, the strain increases sharply. The axial stresses in the pavement are dependent upon the temperature gradient in the slab. Two possible reference temperatures were selected for this analysis:

1. Set temperature.
2. Maximum temperature.

Set time is defined as the time when the concrete is no longer plastic. It has hardened and all stresses at that time are assumed to be zero. Maximum temperature can also be used as a reference if stress relaxation in the early-age pavement is accounted for. It has been found in laboratory testing that stresses in young concrete are substantially relaxed due to high early-age creep.[(2)] This means that after the maximum temperature has been reached, continued relaxation and unloading associated with contraction cause a zero-stress condition to be reach after only a few degrees decrease in temperature. Then as cooling progresses, the tensile stresses start to develop. This behavior is only found in young concrete and not in completely hardened concrete.

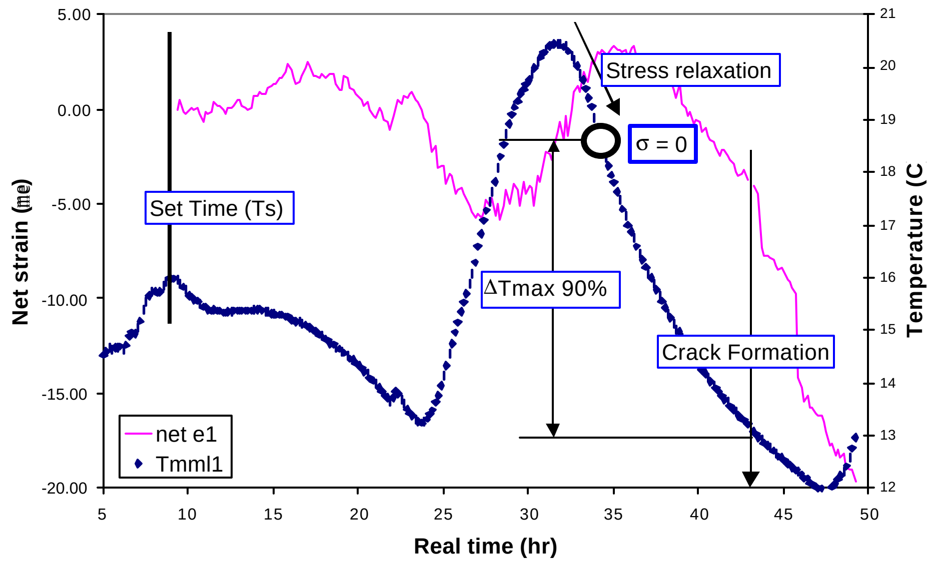

Figure 3. Schematic of stress relaxation in young concrete and determination of ΔT_{max} 90 percent for axial stress (σ_{axial}) calculation.

A schematic of this behavior is presented in figure 3. For the purpose of axial stress calculations, the ΔT_{max} 90 percent is defined as:

$$\Delta T_{max}\ 90\% = 90\%(Tmax - Tset) + Tset$$

Therefore, the stress relaxation in the concrete is accounted for in the axial stress calculation by the ΔT_{max} 90-percent term.

$\sigma_{curling}$

Curling of the slab begins after set time. The LVDT's start to measure the vertical movement of the slab. For this reason, the set time is used to calculate curling stresses in the slab.

$\sigma_{drying\ shrinkage}$

Drying shrinkage stresses have to be accounted for at the top of the slab. HIPERPAV assumes that the drying shrinkage distribution through the thickness of the pavement is as shown in figure 4.

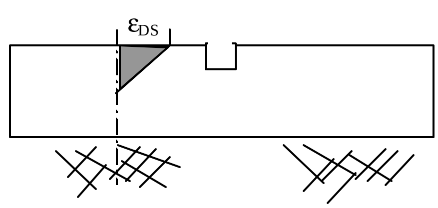

Figure 4. Drying shrinkage distribution through the thickness of the pavement.

Using the experimental drying shrinkage data to calibrate the drying shrinkage model, the drying shrinkage stress is calculated. The middle and bottom of the pavement are not affected by drying shrinkage.

INFLUENCE OF SAW CUT ON CRITICAL STRESSES

The magnitude of the axial stress and the curling stress are affected by the presence of the sawed joint. A saw cut depth of 1/3rd the slab thickness is assumed.

RESULTS OF STRENGTH ANALYSIS

The critical stress has been calculated for all slabs and compared to concrete strength at the time a crack was seen to form experimentally. A summary of results are listed below in table 1. As can be seen, the critical stresses are close to PCC strength in some cases.

Table 1. Summary of critical stress and strength results for PCC pavements in AZ, TX, NC, MN and NE at time experimental crack formed.

	Slab #	**s / s_{fc}** (%)	**Time of cracking** (h)	**e_{DS}** (με)	**s_{axial}** (psi)	**$s_{curling}$** (psi)	**s** (psi)	f_c (psi)
Texas	1	**86**	16.1	0.7	46.3	78.0	**245**	**285**
	2	**84**	14.2	0.6	51.8	63.0	**220**	**260**
	3	136	24.0	1.7	153.0	110.7	479	350
	4	**118**	14.9	1.3	91.8	102.0	**367**	**312**
Nebraska	1	55	16.0	3.3	27.2	38.6	128	234
	2	25	26.3	4.2	46.7	2.7	76	307
Minnesota	1	59	43.5	2.2	86.8	6.2	144	244
	2	50	40.7	2.2	79.4	-0.1	119	239
	3		No cracks					
	4		No cracks					
North Carolina	1	236	13.9	3.8	79.9	104.3	355	150
	2	**84**	33.8	5.9	120.9	16.6	**219**	**260**
	3	139	21.3	3.8	96.0	62.6	285	205
	4	**97**	37.5	5.0	124.0	33.4	**261**	**270**
Arizona	1	42	21.7	3.0	61.0	-17.0	53	127
	3	33	36.4	4.0	46.0	-3	**62**	**190**
	4							
	5	**104**	43.4	5.4	107.0	29.0	226	218
	6	**76**	38.3	5.1	104.0	0.7	**158**	**208**

(E_{creep} used in all calculations. In **Bold** if $\sigma/_{fc}$ = 70-130%).

REFERENCES

(1) Technical Memorandum 298007-22, Analysis of strain gage measurements in TX, MN, NE, NC and AZ instrumented slabs

(2) Emborg, 1989

(3) Technical Memorandum 298007-10, Drying Shrinkage Validation