Relative Performance of CC6 Concrete Pavement Test Items at the FAA National Airport Pavement Test Facility

David R. Brill
Federal Aviation Administration

Izydor Kawa
SRA International, Inc.

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By: David R. Brill, P.E., Ph.D.

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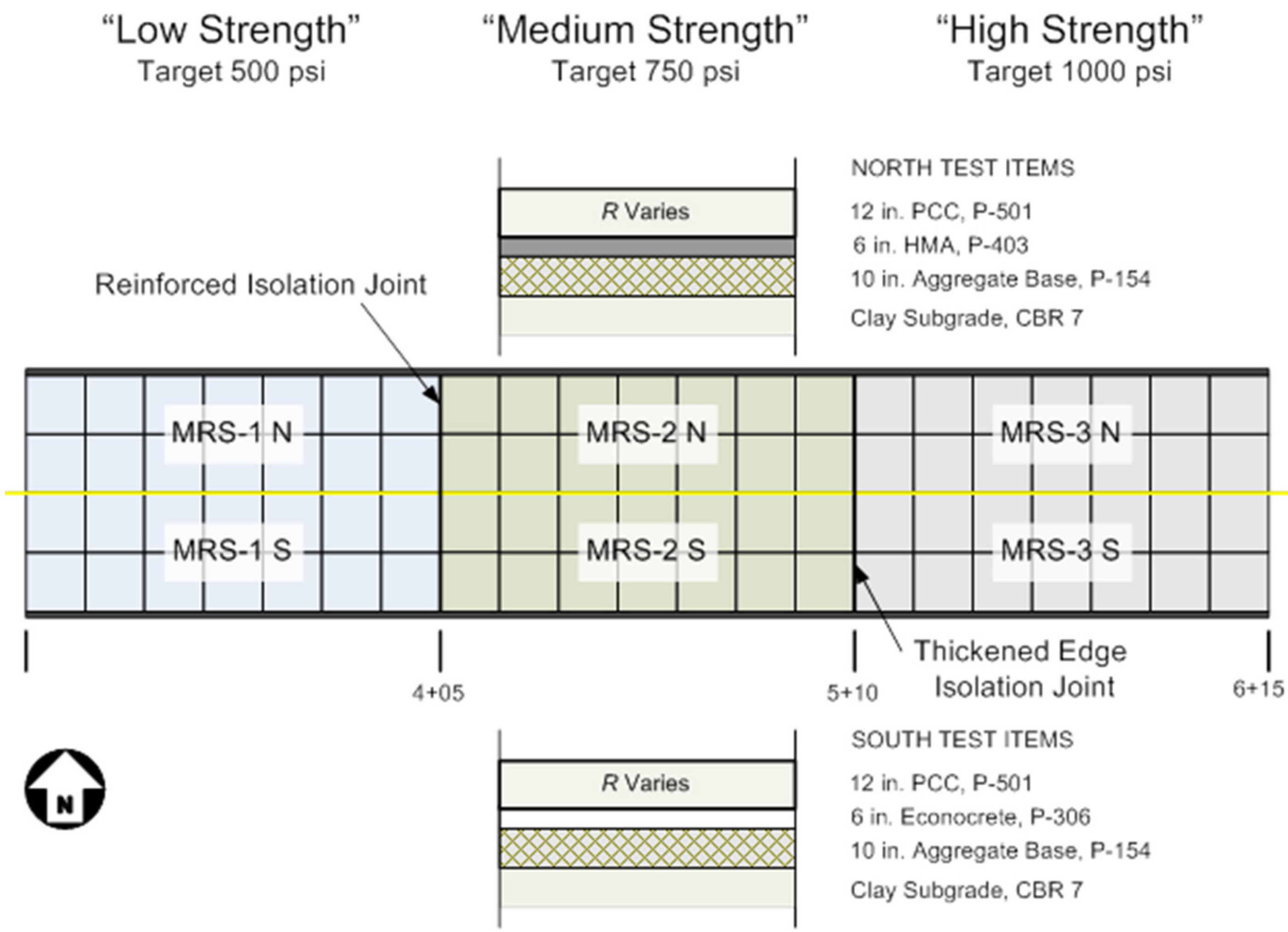
CC6 - Background

- **Tests conducted between August 2011 and April 2012 at the National Airport Pavement Test Facility.**
- **Six rigid pavement test items trafficked to failure.**
  - Three different concrete strengths.
  - Two different stabilized base materials (P-403, HMA and P-306, econocrete).
- **Primary objective was to investigate the effect on pavement life of concrete flexural strengths higher than recommended by current FAA standards in Advisory Circular (AC) 150/5320-6E.**

Effect of High Concrete Strength

- **"Brittleness": Refers to tendency of some engineering materials to fracture at low energy.**
- **In lab tests, very high-strength concrete was associated with increased brittleness relative to normal concrete (Bažant and Planas, 1998).**
- **IPRF 4-1 (2007):**
  - Noted "*very high strength concrete can be brittle and result in lower fatigue life*."
  - Recommended limitations on design flexural strength.
- **However, there is no evidence that any specific concrete strength value in the practical range is associated with reduced pavement life.**

CC6 Test Item Layout



Target vs. Actual Concrete Strength

Test Items	Target Flexural Strength, psi	Mean 28-day Flexural Strength, psi	Standard Deviation of 28-day strength, psi
MRS-1	500	662	48
MRS-2	750	763	113
MRS-3	1000	1007	150

- **28-day strengths based on ASTM C78.**
- **MRS-1 as-placed strength was higher than target.**
  (Still low enough to be statistically separate from MRS-2.)
- **Different materials and proportions were used to obtain the various concrete strengths.**

Concrete Placement Mix Designs for CC6 Test Items

Material	Low-Strength (Target 500 psi)	Med-Strength (Target 750 psi)	High-Strength (Target 1000 psi)
Harmony No. 57 Stone, round, lbs.	1550	N/A	N/A
Penn-Jersey No. 57 Coarse Aggregate, lbs.	N/A	1475	1535
Penn-Jersey No. 9 Intermediate Coarse Aggregate, lbs.	N/A	490	535
Harmony Concrete Sand, lbs.	1414	N/A	N/A
Penn-Jersey Concrete Sand, lbs.	N/A	1225	1070
Water, lbs.	325	230	236
Portland Cement, Type I, lbs.	460	500	680
Air, percent	6.5	7.0	4.5
Air Entraining Admixture, oz.	4.5	5.0	4.5
Target Slump, in.	6.0	5.5	3.5
w/c ratio	0.71	0.46	0.35

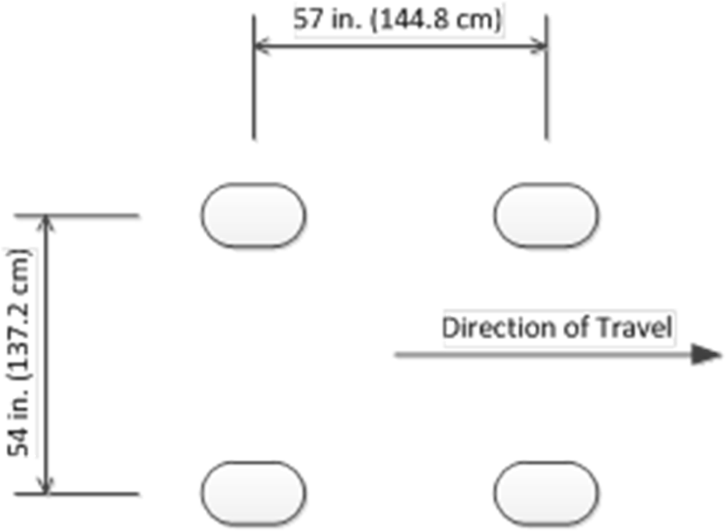
All quantities are per cubic yard of concrete.

CC6 Traffic History

Dates	Wander Patterns	Wheel Load, lbs.	Passes			
			MRS-1 N	MRS-1 S	MRS-2	MRS-3
8 July 2011 – 15 Aug 2011	N/A	44,000	6,970	0	0	0
30 Aug 2011 – 20 Dec 2011	1 – 238	45,000	15,708	15,708	15,708	15,708
27 Dec 2011 – 29 Feb 2012	239 – 405	52,000	0	0	11,022	11,022
29 Feb 2012 – 30 Mar 2012	406 – 508	52,000	0	0	6,978	0
		70,000	0	0	0	6,798
30 Mar 2012 – 25 Apr 2012	509 – 595	70,000	0	0	5,742	5,742
Total Passes:			**22,498**	**15,708**	**39,270**	**39,270**

CC6 Traffic History

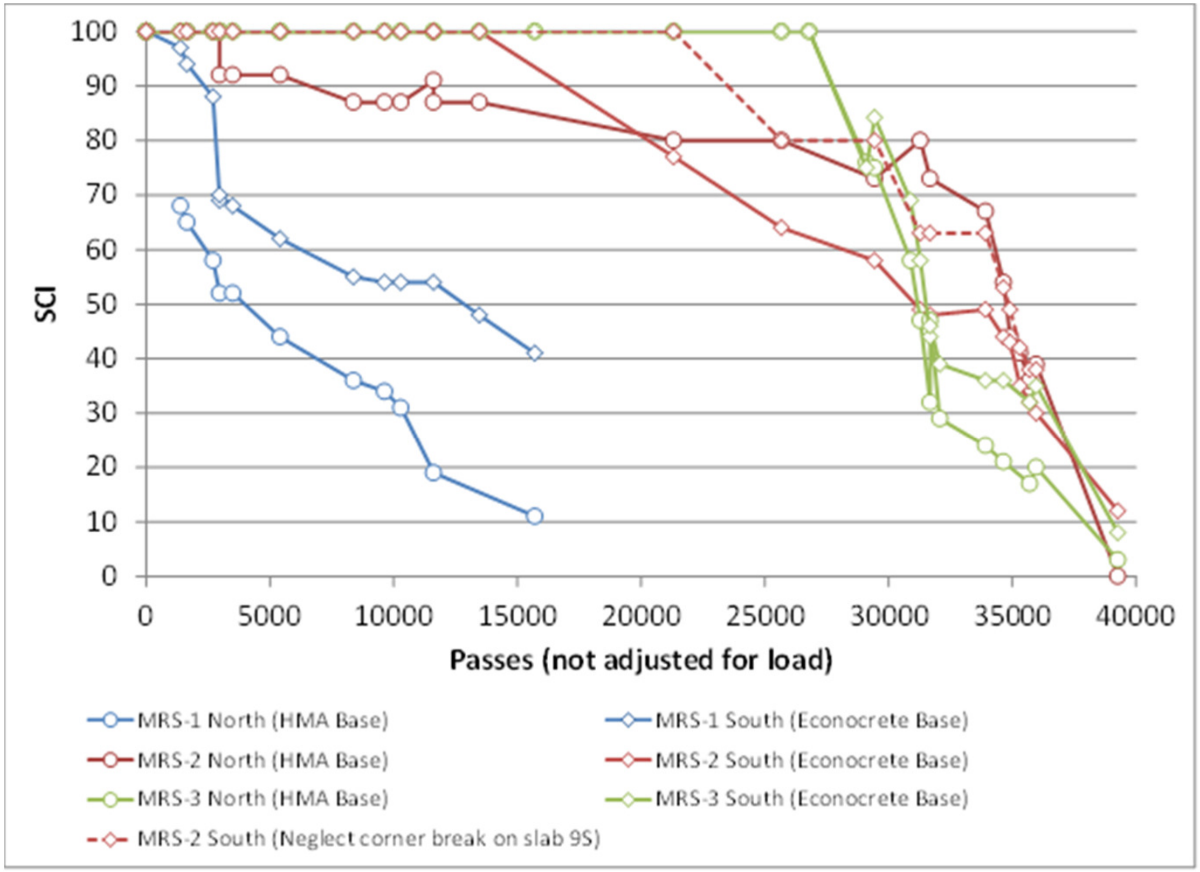
- **Initial traffic wheel load (45,000 lbs.) based on an estimate of 80% of cracking load for MRS-1.**
- **MRS-1 failed after 15,708 passes, but MRS-2 and MRS-3 were essentially undamaged.**
  - Wheel load increased to 52,000 lbs. on both MRS-2 and MRS-3.
  - After additional 11,022 passes, load increased to 70,000 lbs. on MRS-3.
  - After additional 6,798 passes, load increased to 70,000 lbs. on MRS-2.
  - Finally, after additional 5,742 passes at maximum wheel load, all test items had failed.



2D Gear Footprint for CC6 Traffic

SCI* as a Function of Traffic Passes

Does not give a clear picture of the relative performance of test items, because passes have not been adjusted for load.



***Structural Condition Index**

Load Compensation Procedure

- **Need to compensate for mixed traffic, i.e., varying load.**
  - Use Cumulative Damage Factor (CDF) concept.
  - See Hayhoe & Kawa (2013) for a flexible pavement example, which also included temperature.
- **Assume that the rigid failure model takes the form:**

$$C_F = A \times 10^{B\left(\frac{R}{\sigma}\right)}$$

C_F = coverages to failure
σ = concrete stress
R = flexural strength
A, B = parameters

- **The FAARFIELD failure model can be expressed as above.**

Load Compensation Procedure
(continued)

- **Also, consider that failure is defined by:**

$$CDF = \sum_{i=1}^{N} \frac{C_i}{C_{Fi}} = 1$$

N **= number of "aircraft" or distinguishable load levels**
C_i = actual number of coverages for "aircraft" (load) *i*
C_{Fi} = number of coverages to failure for "aircraft" (load) *i* defined by the failure model

- **Thus, the problem for a <u>known failure condition</u> is to find values of parameters *A* and *B* that force CDF = 1.**
- **Simplest procedure is to fix the value of *B* and vary *A* to satisfy the failure conditions.**

Example for CC6, MRS-3 North

- Number of "aircraft" (i.e., distinct combinations of geometry and load) is $N = 3$.
- After determining parameters *A* and *B*, select an appropriate reference wheel load and determine the equivalent number of coverages of the trafficking gear at that wheel load that would cause failure. (Must be done by trial and error).
- Assume for this purpose that the failure condition is SCI = 50.

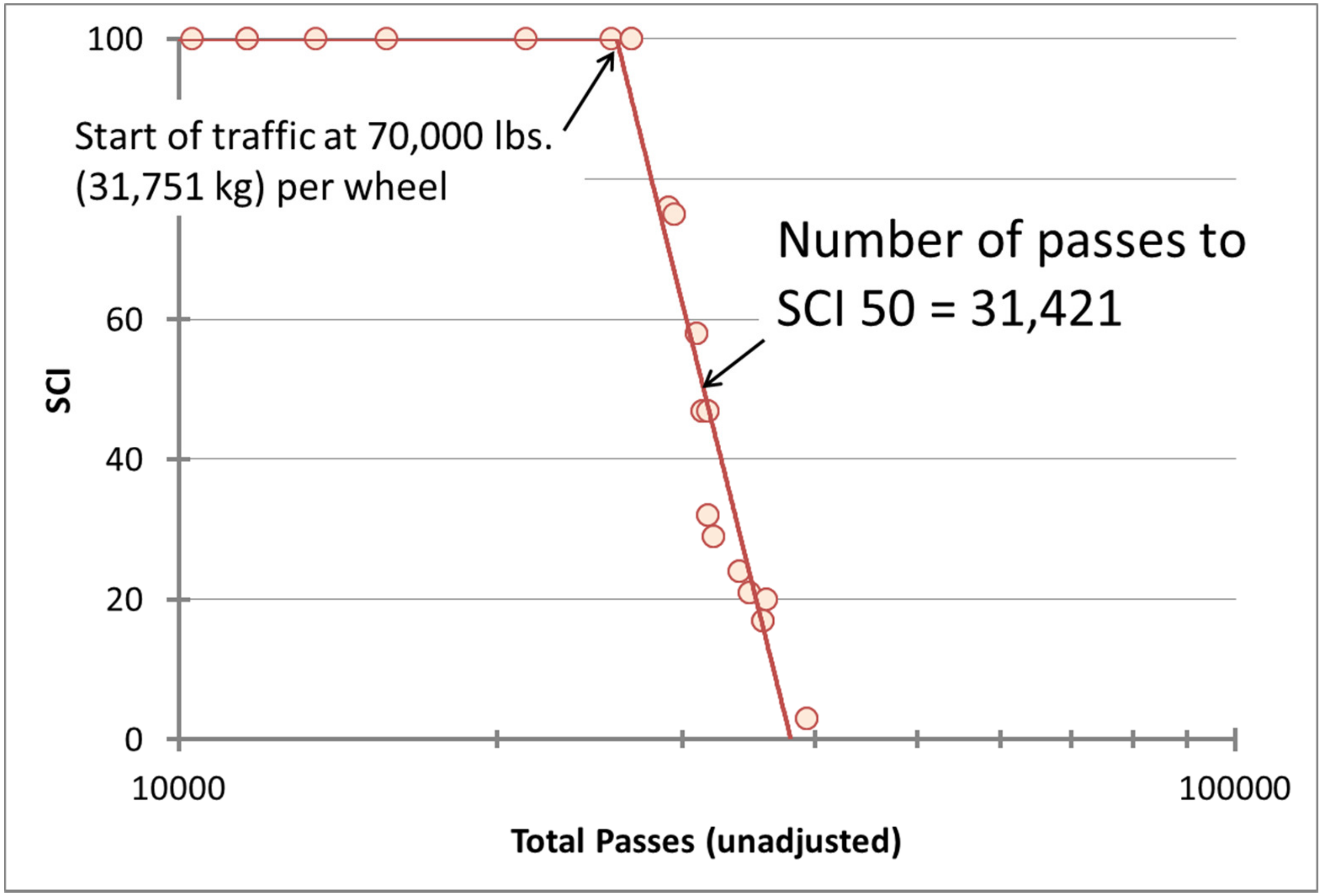
Calculation of Coverages to Failure (SCI 50) Condition for Test Item MRS-3 North

Wheel load, lbs.	Passes	Stress, psi[a]	Pass/Cov.[a]	Coverages
45,000	15,708	$\sigma_1 = 506.3$	4.44	$C_1 = 3538$
52,000	11,022	$\sigma_2 = 572.6$	4.13	$C_2 = 2669$
70,000	4,691	$\sigma_3 = 734.2$	3.57	$C_3 = 1314$

[a] computed using FAARFIELD 1.4

SCI as a Function of Total Passes

Test Item MRS-3 North (High-Strength Concrete)



Example for CC6, MRS-3 North

- **At failure:**

$$CDF = 1.0 = \frac{C_1}{C_{1F}} + \frac{C_2}{C_{2F}} + \frac{C_3}{C_{3F}} = \frac{1}{A} \times \left[\frac{C_1}{10^{\left(\frac{B \times R}{\sigma_1}\right)}} + \frac{C_2}{10^{\left(\frac{B \times R}{\sigma_2}\right)}} + \frac{C_3}{10^{\left(\frac{B \times R}{\sigma_3}\right)}} \right]$$

- **Substituting the known data C_1, C_2, C_3, σ_1, σ_2, σ_3, R = 1000 psi, and assuming B = 6.25 (from FAARFIELD), solve to obtain $A = 4.07 \cdot 10^{-6}$.**
- **Next, calculate equivalent coverages at 70,000 lbs. wheel load.**

Wheel Load, lbs.	Actual Coverages	Equivalent Coverages (at 70,000 lbs. per Wheel)
45,000	3538	0.5
52,000	2669	10.5
70,000	1314	1314
Total	**7521**	**1325**

Equivalent Passes to Failure for 6 CC6 Test Items

Test Item	Failure Model Parameters *A*, *B*	Equivalent Passes at 45,000 lbs./wheel	Equivalent Passes at 70,000 lbs./wheel
MRS-1 North	$5.73 \cdot 10^{-5}$, 6.25	35,653	85
MRS-1 South	$1.53 \cdot 10^{-5}$, 6.25	11,136	25
MRS-2 North	$1.14 \cdot 10^{-4}$, 6.25	915,500	985
MRS-2 South	$1.27 \cdot 10^{-4}$, 6.25	1,215,000	1,224
MRS-3 North	$4.07 \cdot 10^{-6}$, 6.25	39,903,000	4,731
MRS-3 South	$4.33 \cdot 10^{-6}$, 6.25	53,732,000	5,832

CC6 Test Results
Based on Equivalent Passes at Reference Load

- CC6 test items were clearly differentiated by concrete strength.
- Higher strength corresponds to longer equivalent life (MRS-3 > MRS-2 > MRS-1).
- No "optimal" concrete strength identified from these full-scale tests.
- Brittle effects do not appear to cause a reduction in rigid pavement fatigue life under aircraft traffic.

Relevance to Concrete Strength in Design Model

- **FAARFIELD design model assumes that rigid pavement fatigue life is strongly correlated to the 28-day concrete strength.**
  - CC6 full-scale test results reconfirmed this.
  - However, the observed increase in pavement life at high strength is not as great as predicted by the current FAARFIELD failure model.

Compared with 5-35 in the full-scale test.

Predicted Passes to Failure Based on FAARFIELD 1.4:

PCC Strength, psi	Wheel Load, lbs.	Predicted Life (Passes to Failure)	Ratio
660	45,000	585	13
750	45,000	7551	
750	70,000	8	136
1000	70,000	1089	

Effect of Base Layer Type

- **No significant difference in SCI versus traffic was observed for rigid test items on HMA bases (north test items) and econocrete bases (south test items).**
- **However, some qualitative differences in crack patterns were observed.**
  – A greater proportion of the total distress on econocrete-base test items was contributed by corner breaks, as opposed to longitudinal or transverse cracks.
  – Suggests that the use of a single number (SCI) to characterize performance may obscure some critical differences in structural behavior.

Conclusions

- **CC6 full-scale test results support the principle that concrete flexural strength is the major material property influencing rigid pavement life.**
- **A rational load compensation procedure was used to account for mixed traffic loading on CC6 test items.**
  - All traffic was converted to equivalent passes of a reference vehicle load.
  - When compared on the basis of equivalent passes at the reference load, test item performance consistently ranked according to 28-day concrete strength.
- **Based on these test results, some relaxation of the current AC limitations on concrete strength in thickness design is advisable.**

Questions?

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