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Development of Airport Groove Identification Program ProGroove

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SRA International Inc.

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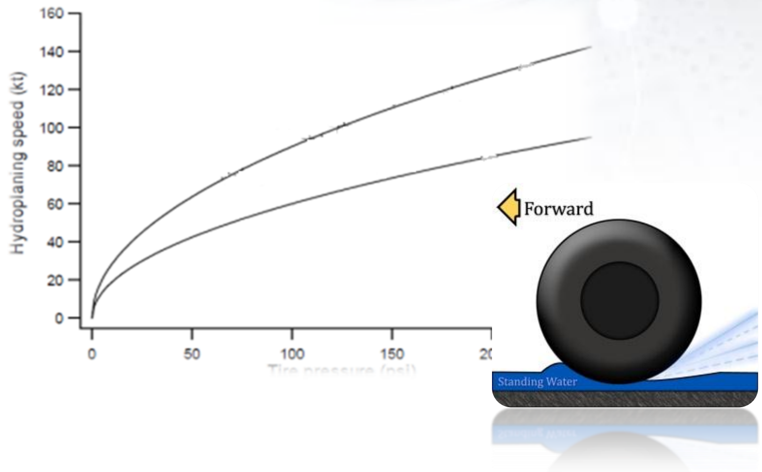
Outline

- Introduction to Airport Runway Grooves
- Groove Identification Program: ProGroove
- Tire Contact Model and Algorithm of Beam Bridging Filter
- Groove Identification Using ProGroove
- ProGroove with High Resolution Sensor

Introduction to Airport Runway Grooves

Tire Hydroplaning

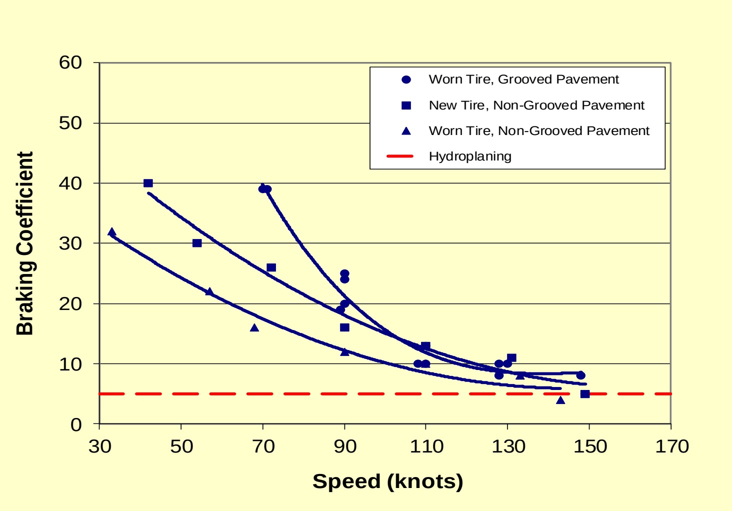
When aircraft tires or highway vehicle tires roll over water covered or flooded pavements, water may penetrate between the tire and the pavement. This penetration results in the formation of water pressure which raises a portion of the tire off the pavement.



This pressure increases as the speed of the vehicle increases, supporting more and more of the tire, until, at a critical speed termed the hydroplaning speed, the tire is supported only by the water and loses all contact with the pavement.

Introduction to Airport Runway Grooves

From 1975 to 1983, The Federal Aviation Administration (FAA) made a series of full scale tests of aircraft braking and hydroplaning on grooved asphalt and rigid runways.



It has been found that cutting or forming transverse grooves in a pavement, which allows the water to be ejected from beneath the tires of an aircraft moving at high speed, is a proven and effective technique for reducing the hydroplaning.

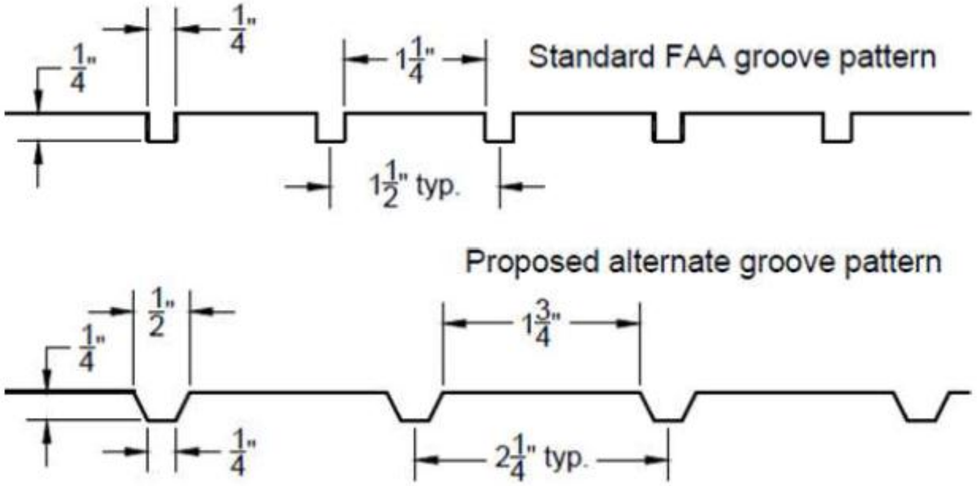
Reference: Daiutolo, H. "Runway Grooving and Surface Friction". 10th ALACPA Airport Pavement Seminar. Mexico City, Mexico. September 30 to October 4, 2013.

Introduction to Airport Runway Grooves

Groove Configuration

The FAA standard groove configuration is 1/4 inch (6 mm) in depth by 1/4 inch (6 mm) in width by 1 1/2 inch (38 mm) center to center spacing.

*--- **FAA: AC 150/5320-12C***

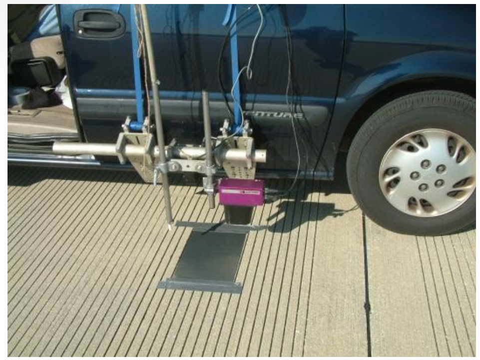


Reference: Patterson, J. “Evaluation of Trapezoidal-Shaped Runway Grooves,” Report No. DOT/FAA/TC-TN12/7. FAA William J. Hughes Technical Center, May 2012.

Introduction to Airport Runway Grooves

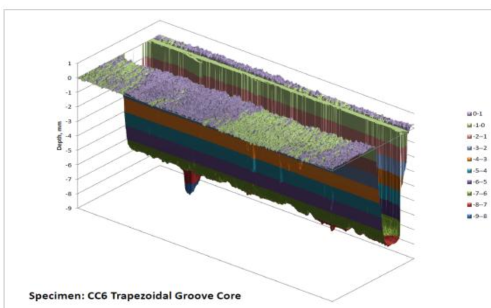
Groove Measurement at NAPTF

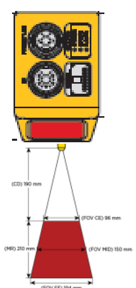
Manual measurement



Mobile profiler

Truss profiler





High Resolution Portable Profiler

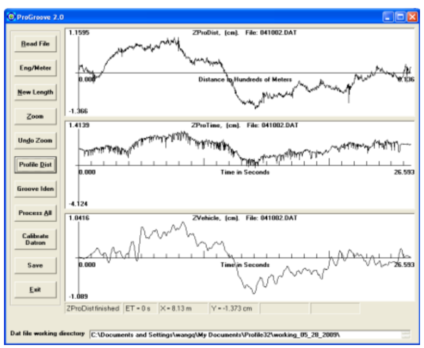
Grooves on pavement

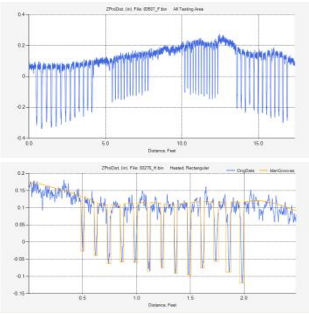
Groove Identification Program: ProGroove

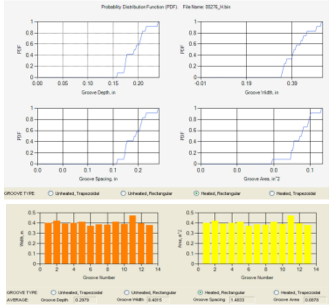
The computer program, ProGroove, was developed which automatically identifies grooves in an elevation profile and computes the dimensions of the grooves.

ProGroove software can remove the groove-like disturbances of joints in concrete pavements from the counted grooves.

ProGroove provides the groove number, location, depth and width, as well as a series of statistical results for groove quality analysis.



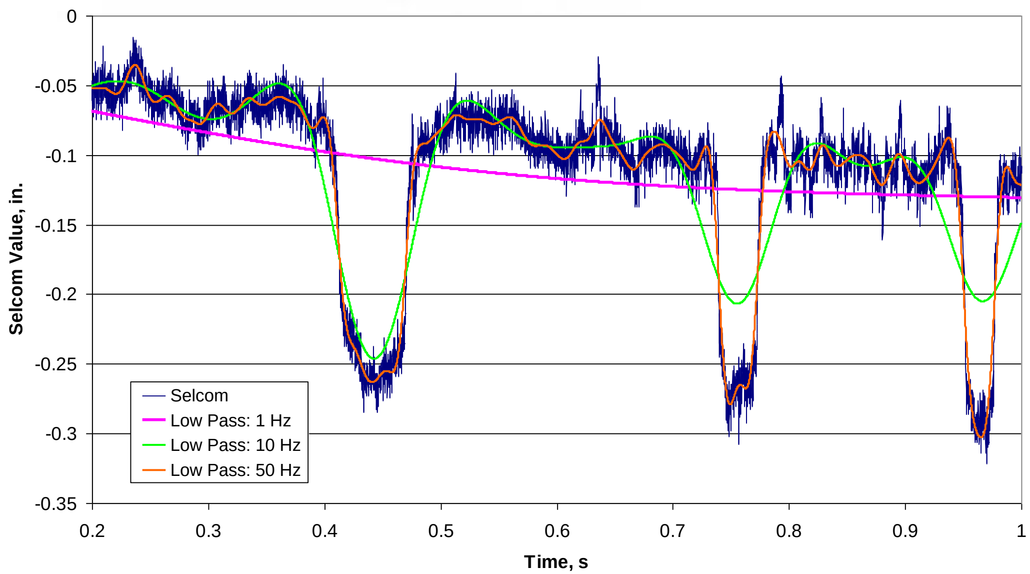


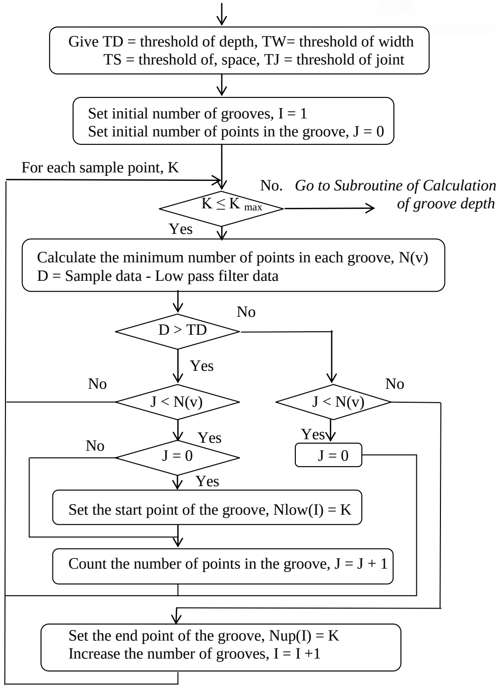


Reference: Rapol, J. L. and Wang, Q. "Automatic Runway Groove Identification and Evaluation". 2010 FAA Worldwide Airport Technology Transfer Conference. *http://www.airporttech.tc.faa.gov/ATT2010.*

Groove Identification Program: ProGroove

The calculation is performed by comparing the vertical distance between individual profile data points with the corresponding low-pass filtered data points.



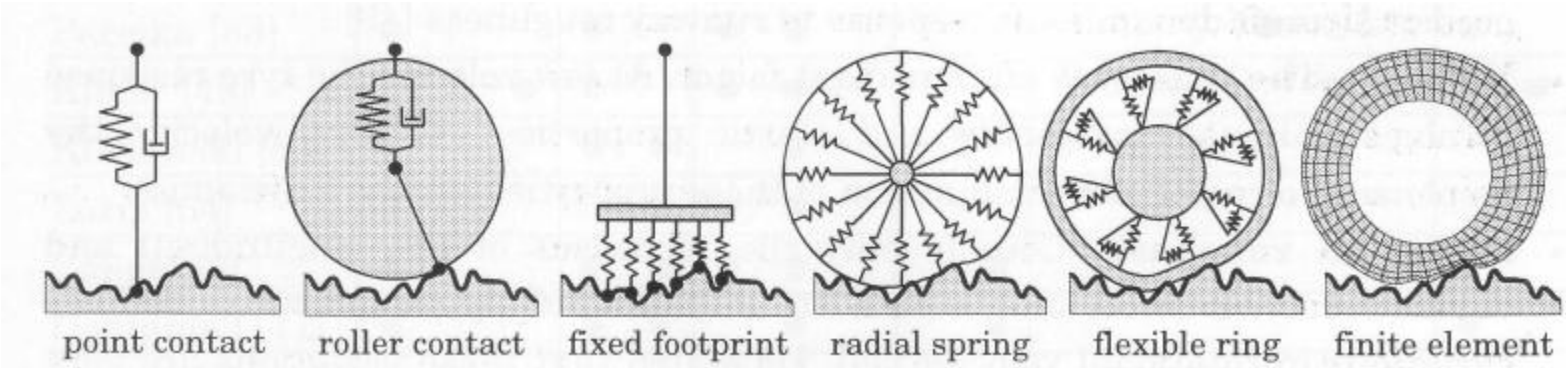


An algorithm of tire-pavement contact model was developed to replace the low-pass filter.

Tire Contact Model of Beam Bridging Filter

Many researchers have studied vehicle tire and pavement interaction and have developed different mathematical models.

ProGroove applied a new mechanical model to reduce the influence of short dips in the measured profiles.

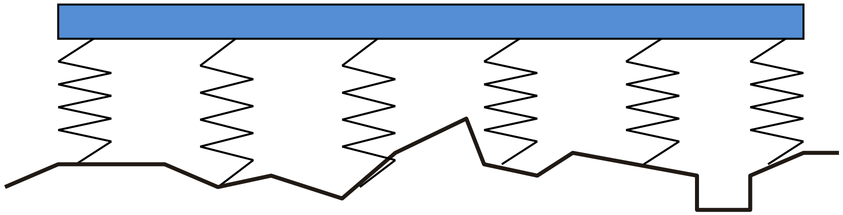


Reference:

- *K.M. Captain & et al. "Analytical Tire Models for Vehicle Simulation". Vehicle System Dynamics 8, pp. 1-32. 1979.*
- *S. M. Karamihas. "Critical Profiler Accuracy Requirements". The University of Michigan Transportation Research Institute Report, Sept., 2005.*

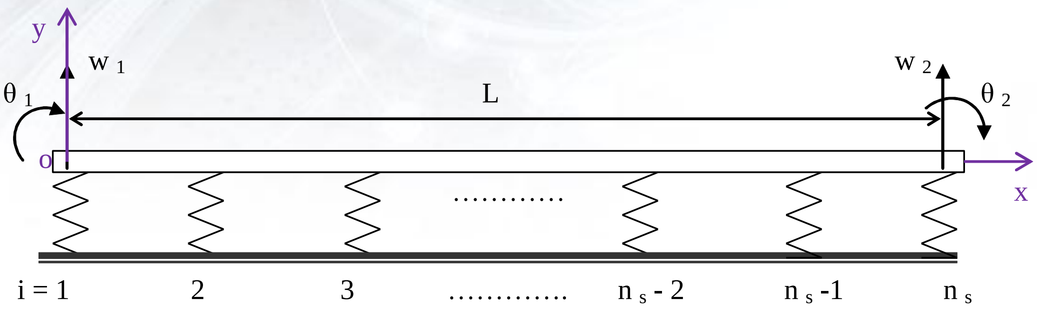
Tire Contact Model of Beam Bridging Filter

The filtering method, known as a "Beam Bridging Filter" was developed to improve the filtering quality of using existing filters. It can be implemented to the program of runway roughness analysis and groove identification.



- Adjusts the effect of the contact between a tire and the road surface by modeling the contact area as a beam element with a series of compressive springs.
- Remove the tensile spring stress so that only compressive stress exists in the simulated contact element between the tire and the pavement surface.

Algorithm of Beam Bridging Filter



Express displacements along the beam using shape functions

$$w(x) = w_1 N_1(x) + \theta_1 N_2(x) + w_2 N_3(x) + \theta_2 N_4(x)$$

$$N_1(x) = 1 - \frac{3x^2}{L^2} + \frac{2x^3}{L^3}, \qquad N_2(x) = x - \frac{2x^2}{L} + \frac{x^3}{L^2}$$

$$N_3(x) = \frac{3x^2}{L^2} - \frac{2x^3}{L^3}, \qquad N_4(x) = -\frac{x^2}{L} + \frac{x^3}{L^2}$$

$$B_1(x) = -\frac{d^2 N_1(x)}{dx^2} = \frac{6}{L^2} - \frac{12x}{L^3}, \qquad B_2(x) = -\frac{d^2 N_2(x)}{dx^2} = \frac{4}{L} - \frac{6x}{L^2}$$

$$B_3(x) = -\frac{d^2 N_3(x)}{dx^2} = -\frac{6}{L^2} + \frac{12x}{L^3}, \qquad B_4(x) = -\frac{d^2 N_4(x)}{dx^2} = \frac{2}{L} - \frac{6x}{L^2}$$

Algorithm of Beam Bridging Filter

Stiffness matrix for the beam element

$$[K_b] = \int_0^L [B_1(x) \quad B_2(x) \quad B_3(x) \quad B_4(x)] \cdot EI \cdot \begin{bmatrix} B_1(x) \\ B_2(x) \\ B_3(x) \\ B_4(x) \end{bmatrix} dx$$

$$[K_b] = \frac{EI}{L^3} \begin{bmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^2 & -6L & 2L^2 \\ -12 & -6L & 12 & -6L \\ 6L & 2L^2 & -6L & 4L^2 \end{bmatrix}$$

Solve the equilibrium equation

$$([K_b] + [K_s]) \begin{bmatrix} w_1 \\ \theta_1 \\ w_2 \\ \theta_2 \end{bmatrix} = [F]$$

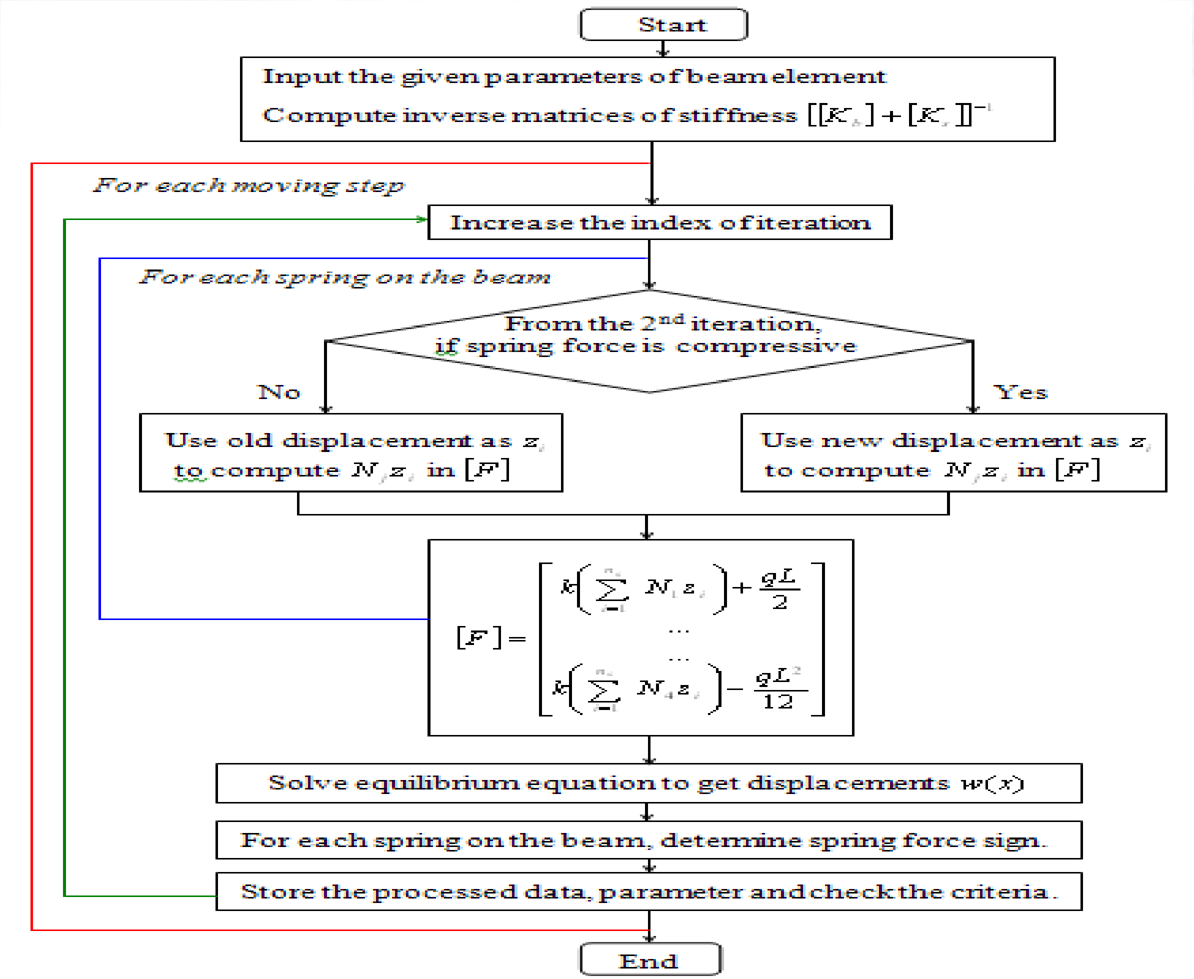
Spring potential energy Π on the beam

$$\Pi = \sum_{i=1}^{n_s} \Pi_i = \frac{k}{2} \sum_{i=1}^{n_s} (w(x_i) - z_i)^2$$

$$\Pi = \frac{k}{2} \sum_{i=1}^{n_s} (w_1 N_1(x_i) + \theta_1 N_2(x_i) + w_2 N_3(x_i) + \theta_2 N_4(x_i) - z_i)^2$$

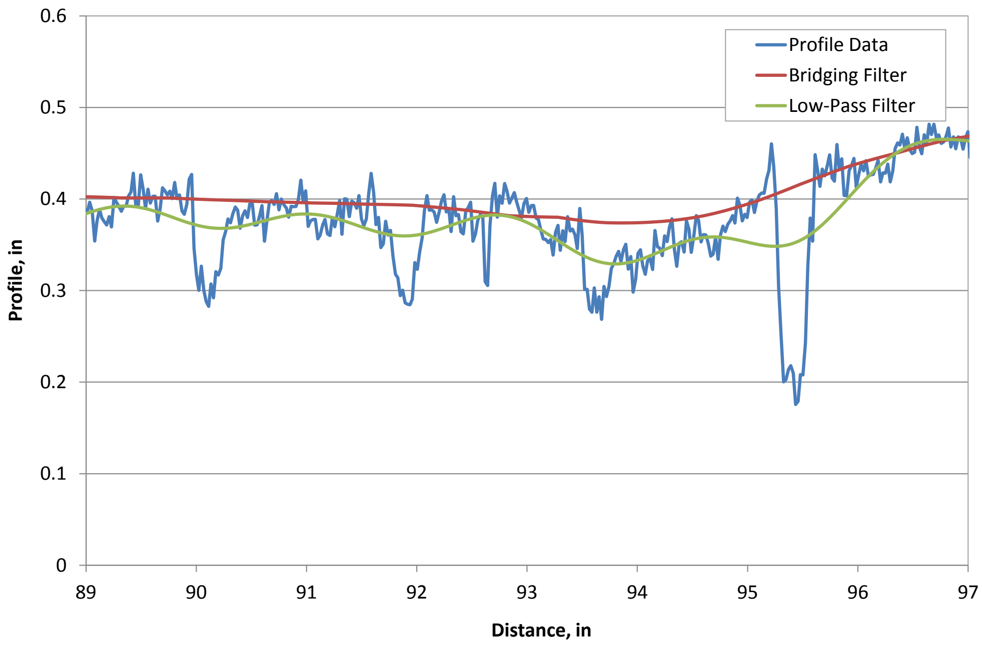
$$[K_s] = k \begin{bmatrix} \sum_{i=1}^{n_s} N_1^2 & \sum_{i=1}^{n_s} N_1 N_2 & \sum_{i=1}^{n_s} N_1 N_3 & \sum_{i=1}^{n_s} N_1 N_4 \\ \sum_{i=1}^{n_s} N_2 N_1 & \sum_{i=1}^{n_s} N_2^2 & \sum_{i=1}^{n_s} N_2 N_3 & \sum_{i=1}^{n_s} N_2 N_4 \\ \sum_{i=1}^{n_s} N_3 N_1 & \sum_{i=1}^{n_s} N_3 N_2 & \sum_{i=1}^{n_s} N_3^2 & \sum_{i=1}^{n_s} N_3 N_4 \\ \sum_{i=1}^{n_s} N_4 N_1 & \sum_{i=1}^{n_s} N_4 N_2 & \sum_{i=1}^{n_s} N_4 N_3 & \sum_{i=1}^{n_s} N_4^2 \end{bmatrix}$$

Algorithm of Beam Bridging Filter



Advantages of Using Beam Bridging Filter

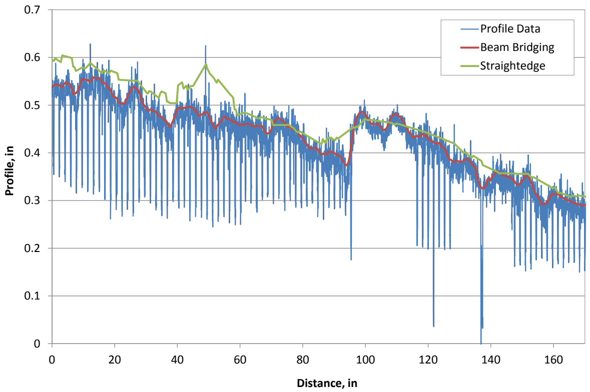
Using the beam bridging filter yields a more stable line that is not much influenced by the groove valley. The example demonstrates that using the beam bridging filter leads to improved groove identification over implementation of current low-pass filters.



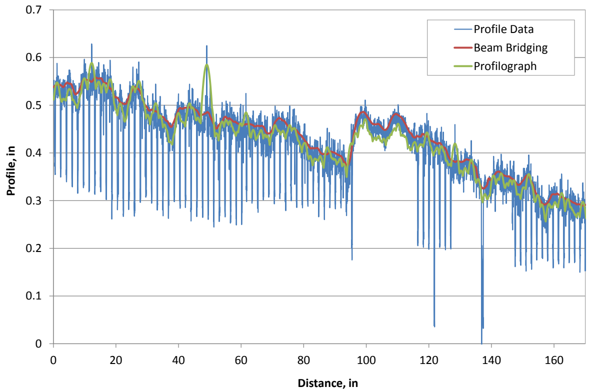
Advantages of Using Beam Bridging Filter

The contact model of Beam Bridging Filter is designed to mimic the contact phenomenon between a tire and the pavement surface by using a series of compressive springs on the beam element.

The Beam Bridging Filter is compared with other bridging filter types and shown to be more suitable for processing of runway profile testing data.



Straightedge filter



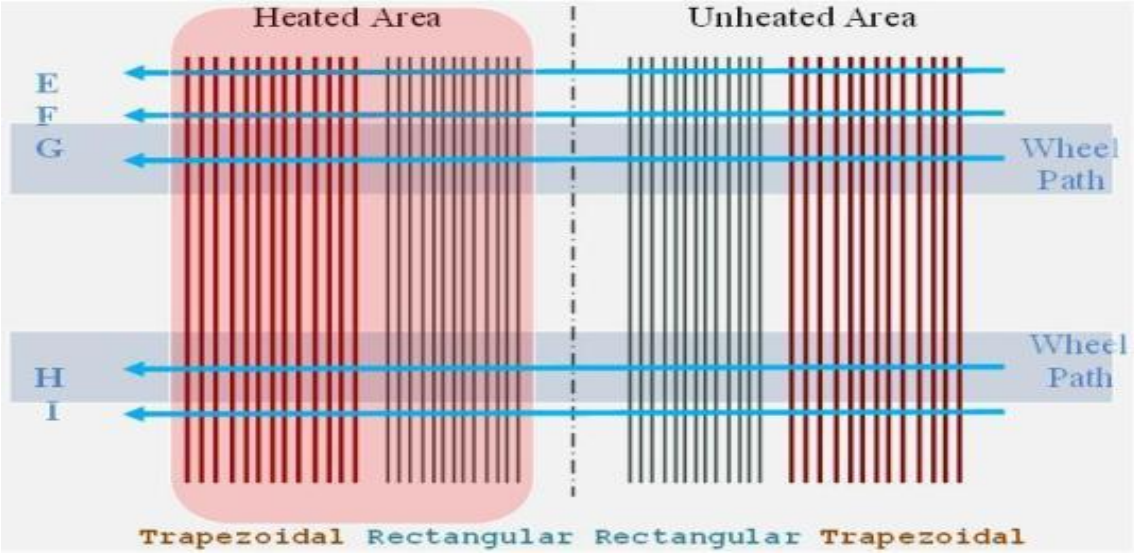
Profilograph wheel filter

Reference: Wang, Q. and Hayhoe, G. F. “Development and Implementation of a Beam-Bridging Filter for Use in Airport Groove Identification”. Journal of the Transportation Research Board. Volume 2369 / Pavement Management 2013, Vol. 4.

Groove Identification Using ProGroove

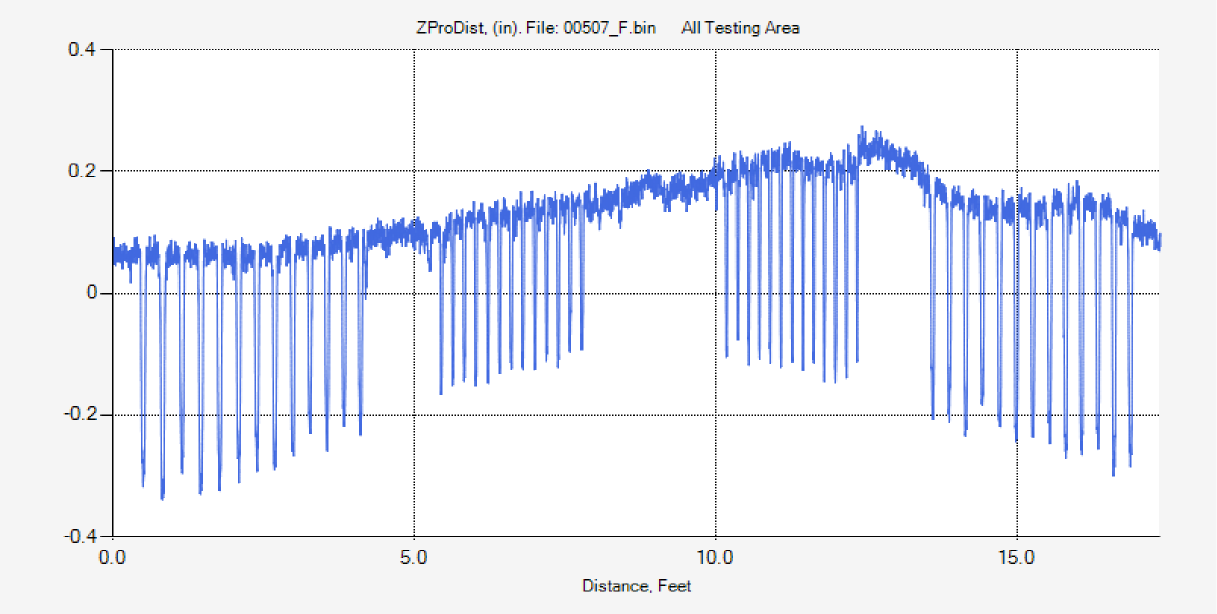
Two groove patterns of trapezoidal and rectangular grooves under aircraft tire loading with service life were constructed and conducted on flexible and rigid pavement respectively. The parameters on the flexible pavement are

- Four sections of grooves: heated/unheated trapezoidal, heated/unheated rectangular. Heated surface temperature is 115 ºF (46 ºC).
- Five test wheel path lines: E, F, G, H, I.



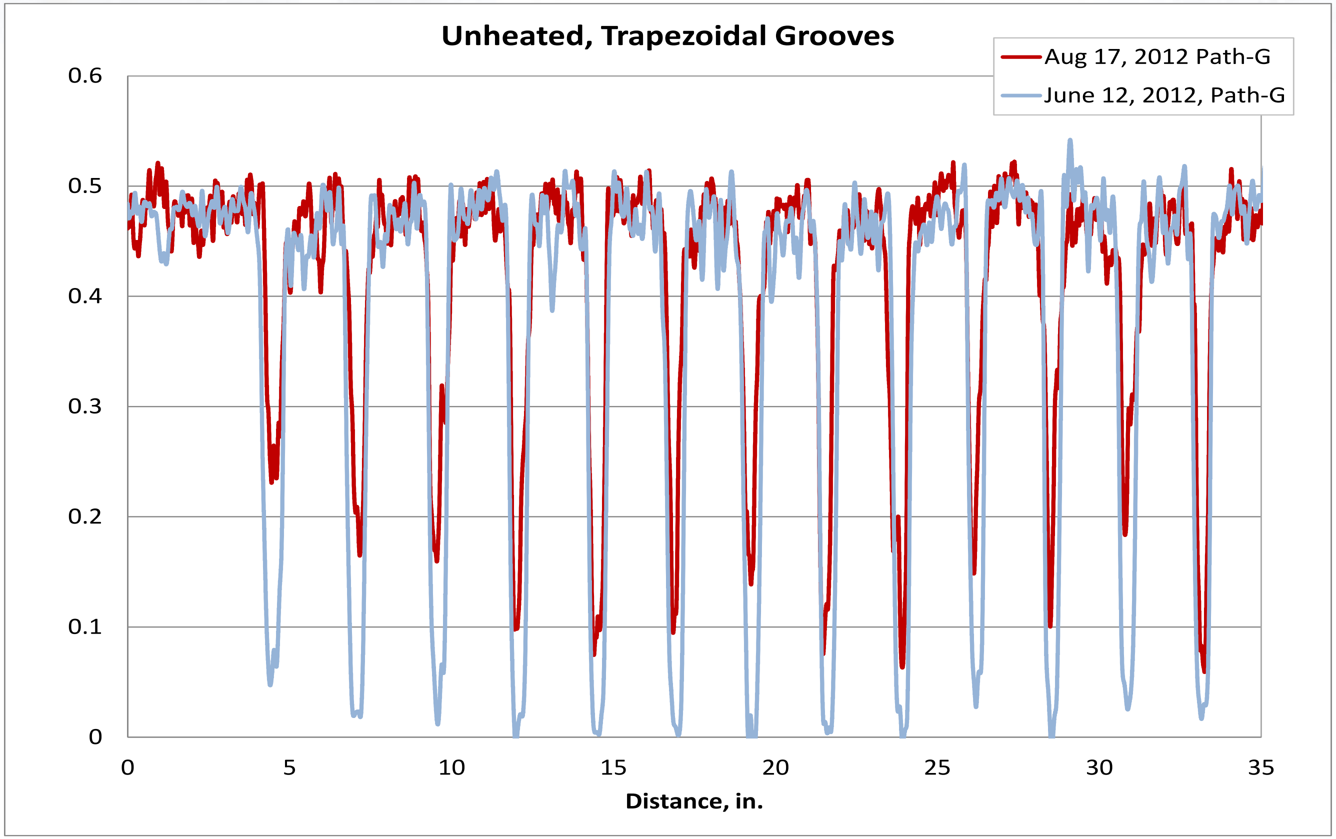
Groove Identification Using ProGroove

- The loading value in the wheel path G (245 psi / 1448 kPa) is greater than in the wheel path H (210 psi/ 1689 kPa).
- Four types of groove test data are assembled in a file.
- Profiler test speed is not a constant along the test line.
- Challenge: find the break points to split the file into four sections.



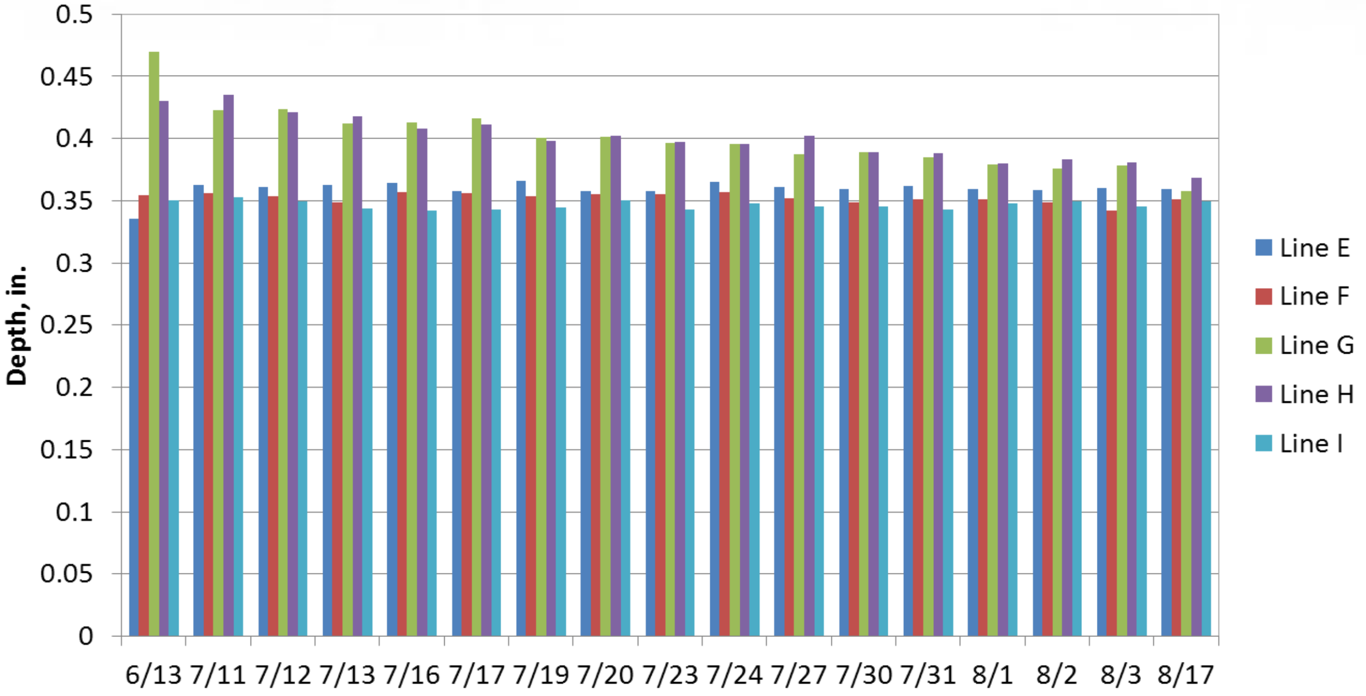
Groove Identification Using ProGroove

Groove shape comparison at path G between June 12 to Aug 17, 2012.



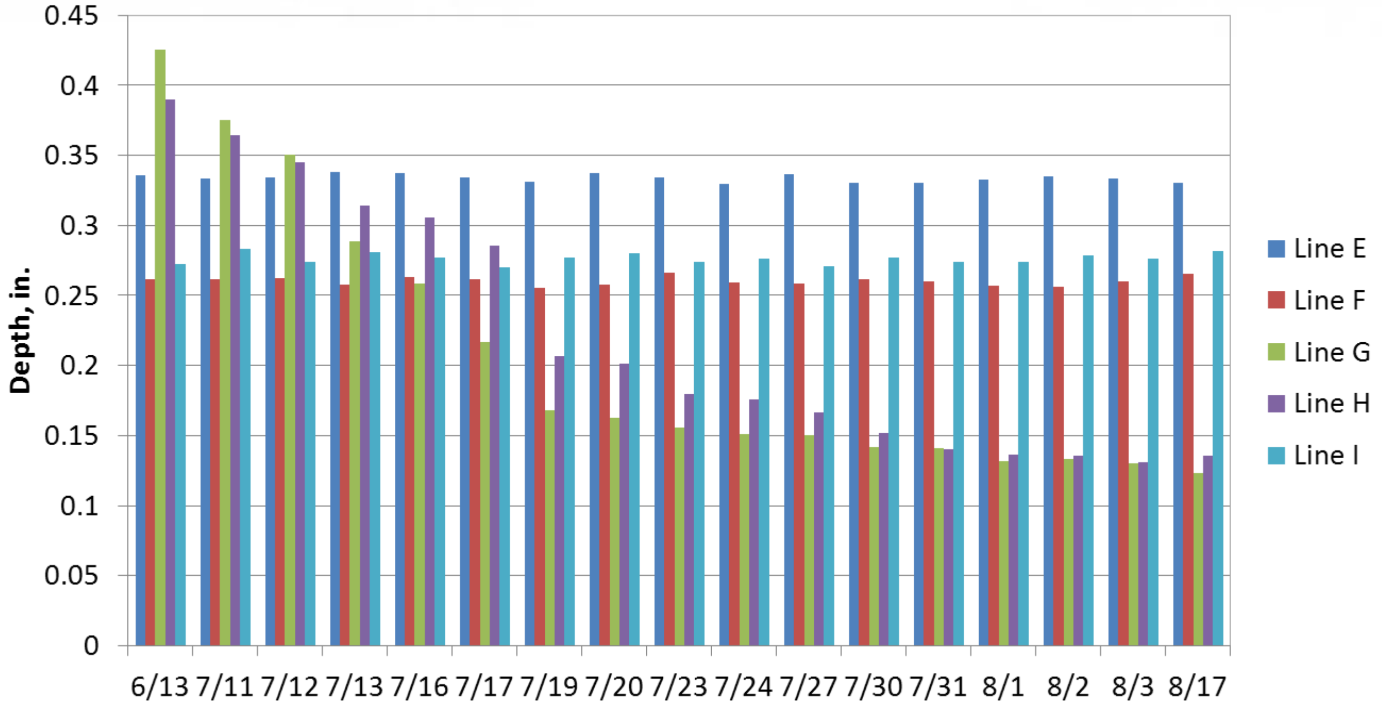
Groove Identification Using ProGroove

Groove depth of unheated trapezoidal area.



Groove Identification Using ProGroove

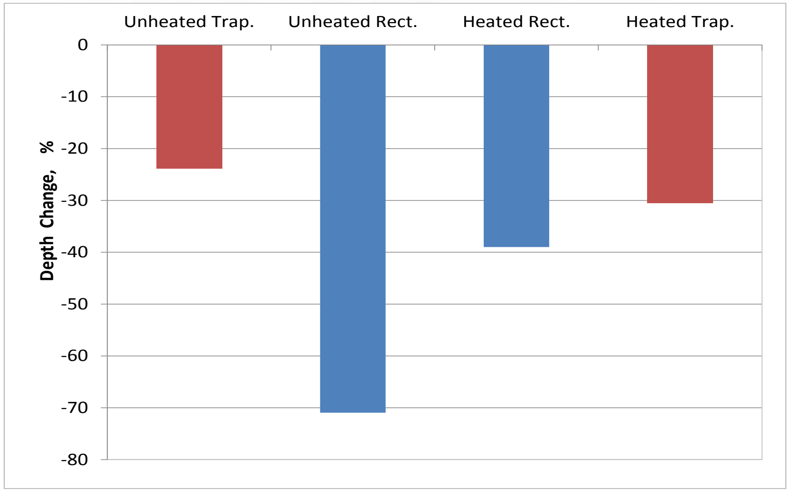
Groove depth of unheated rectangular area.

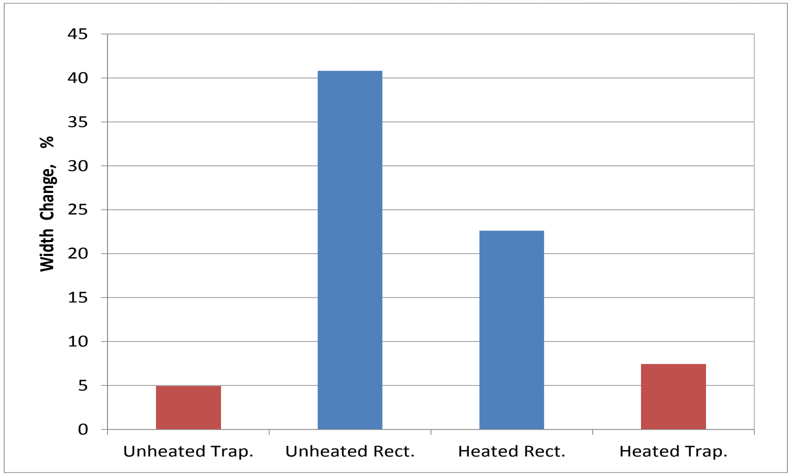


Groove Identification Using ProGroove

Percentage of groove depth and width changes at path G

(From 06/12/2012 to 08/17/2012)





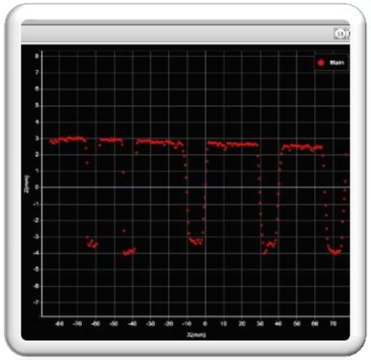
The results show that the trapezoidal grooves maintain better shape stability than rectangular grooves on flexible pavement areas.

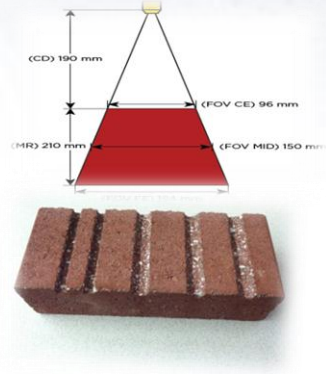
Reference: Wang, Q. and Davis, J. "Airport Pavement Groove Identification and Analysis at NAPTF". Advanced Materials Research, Vol. 723. Page 1003-1010. 2013.

ProGroove with High Resolution Sensor

Sensor Parameters

Data points: 1280 per line
Scan rate: 5000 Hz
Resolution Z: 0.03 mm,
Resolution X: 0.17 mm.



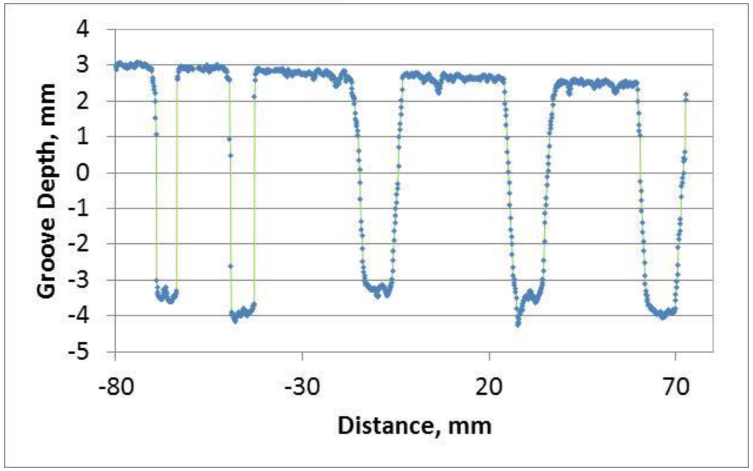


Groove Shape Identification

- Width
- Depth
- Angles
- Cross section area

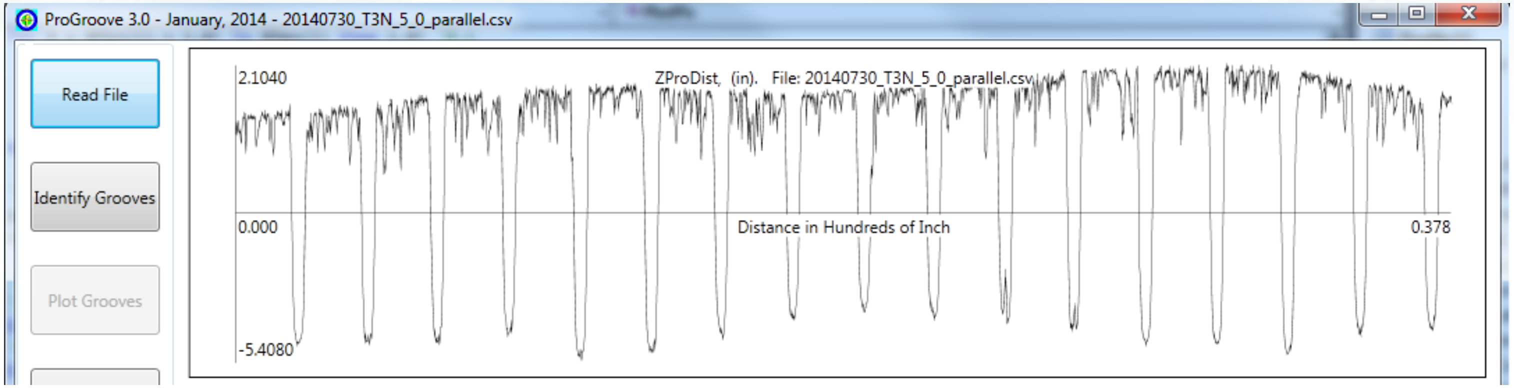
Groove Texture Analysis

- Mean profile depth
- Mean texture depth



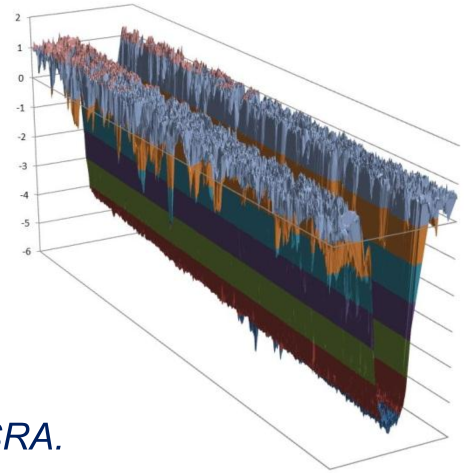
ProGroove with High Resolution Sensor

Test data of CC7 groove area at National Airport Pavement Test Facility



Evaluate Grooves on the Flexible Pavement during Loading Period

- Rectangular and trapezoidal grooves
- Surface texture on the grooving area
- Groove geometry changes



The test was operated by Steve Augustyn and Peter D'Amico, SRA.

Thank You!

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