Airport Pavement Roughness Index Relationships Using the Federal Aviation Administration (FAA) Profiling System

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Abstract

The Federal Aviation Administration (FAA) airport pavement profiling system is introduced. This system consists of an inertial profiling device specifically designed for measuring longitudinal elevation profiles of airport pavements and a computer program for analyzing the measured profiles and computing roughness and smoothness index values. Profiles were measured at sixteen airports using the profiling device and straightedge index values were computed using the associated software. The index values were calculated using computer simulations of two types of straightedge (normal and rolling), four different straightedge lengths (9.8-, 12,-, 16-, and 25-ft), and two different procedures for finding the maximum profile deviations from the straightedge (along the full length of the straightedge and between the supports). Reliable relationships between the index values for different straightedge configurations are developed. The relationships between rolling and normal straightedge indexes are somewhat less reliable than those between different configurations of normal straightedges, indicating that the rolling straightedge has somewhat different evaluation characteristics than the normal straightedges.

Introduction

Current FAA requirements for measuring pavement surface profile characteristics consist of acceptance specifications for new pavement construction based on measurements made with physical straightedges (FAA AC 150/5370-10B). Substitution of physical California Profilometer measurements for some portions of the acceptance requirements is also allowed by exception. But modern practice has seen the development of automatic profiling devices and computer simulation of the physical devices to give software generated versions of the pavement evaluation indexes and performance metrics. Most of the modern methods have been developed for evaluating the performance of highway pavements and the direct application of the highway methods to airport practice is not necessarily valid because of different operating conditions and different vehicle characteristics. For example, aircraft operate over a much wider speed range than highway vehicles, spend most of the takeoff roll accelerating, have much higher tire pressures and tire contact areas, and expose passengers and operating personnel to pavement generated disturbances for much shorter periods of time than highway vehicle passengers and drivers are exposed to. In terms of automatically measuring airport pavement profiles, significant portions of runways and taxiways cannot be measured at constant speed, as is typically required by highway profiling devices, because acceleration and deceleration areas are not normally available to the measuring vehicle. And the runways at most large U.S. airports are transversely grooved to reduce hydroplaning potential. A need therefore exists for profiling devices which can accurately and efficiently measure airport pavement surface profiles and to verify how well highway evaluation procedures apply to similar evaluation needs at airports.

The FAA has developed an inertial profiling device (profiler) specifically for measuring longitudinal profiles of airport pavements. The device is small and light enough to be transported by air as checked luggage so that it can be moved to an airport quickly and at low cost. The data processing software was also designed so that profiles suitable for computing simulated aircraft responses and common surface profile indexes can be recorded over the full length of runway and taxiway pavements. At the same time, a separate computer program was developed to process the profile data. The program is called ProFAA and can compute the most common indexes and response metrics used for acceptance of new pavements and evaluation of pavement condition.

Profiles have been measured with the profiler at sixteen airports representative of U.S. commercial and large international airport operations. These profiles have been analyzed with ProFAA to determine the correlation between the current FAA new pavement acceptance methodologies and other common, or proposed, methodologies. The results of this analysis are presented.

The FAA Profiling System

The FAA profiling device has the same collection of components as a typical modern inertial profiling device used to measure highway profiles: vertical accelerometer, non-contact vertical displacement transducer, and non-contact distance traveled transducer. The three transducers are mounted on a portable frame which is mounted on the door of a standard sedan car or van by means of adjustable straps. Power is supplied from a single 12 volt supply and data is collected with a standard laptop computer. The device can be transported disassembled as checked luggage and then assembled and mounted on a rental vehicle to make the measurements at the airport. A deficiency of inertial based systems is that errors are introduced into the vertical accelerometer signal whenever the vehicle accelerates or decelerates. The major effects of these errors are removed from highway system devices by high-pass filtering the accelerometer signal and, providing that acceleration and braking are kept to a minimum during measurement, the errors introduced into the computation of typical highway roughness indexes are negligible. But on a typical airport pavement it is usual to measure the profile from threshold to threshold of a runway or from end to end of a taxiway. The FAA device allows this to be done by assuming that the measuring vehicle can be modeled as a simple car with a pitch degree of freedom only and using a parameter estimation procedure in the data processing program to remove the major part of the induced accelerometer errors. Details of typical configurations, minimum specifications, and operating procedures for highway inertial profiling devices can be found in (ASTM E 950-98). A list of references describing the development of inertial devices is also included in (ASTM E 950-98). Details of the FAA device and its data processing procedure are given in (Hayhoe et al., 1998).

Raw data from the FAA device is initially recorded at 32 kHz and then processed, smoothed, and decimated to a constant spatial spacing of 25 mm (0.9843 in, 0.082 ft), and stored in a data file for input to ProFAA. Data analysis performed by ProFAA includes the simulation of the following devices and/or evaluation procedures.

- Straightedge (simulation of a physical straightedge)
- Rolling Straightedge
- Boeing Bump (see (Boeing, 1995))
- IRI
- California Profilograph (PI)
- RMS Bandpass
- Aircraft Simulations (four representative commercial models)

A copy of the program can be downloaded from reference (FAA AAR-410 Website) together with a draft user's manual.

Indexes are calculated for each of the methods based on either the standard definition, as for IRI, or as an average over a specified length. The profile is typically split into 500-ft or 1,000-ft (152.4-m or 304.8-m) sections and the index calculated for each

section. An index is also calculated for the full length of the profile. Only indexes calculated over the full length of the profiles are presented in this paper.

Straightedge Indexes

Physical straightedges are currently the devices most used for smoothness acceptance of new airport pavements, both commercial and military. Their simulation on automatically measured profiles is therefore important, if only to establish correlations with other replacement methods. A proposed replacement is what is here called a rolling straightedge. A physical implementation of a rolling straightedge has a beam mounted on supports at the ends of the beam. The distance from the beam to the surface of the pavement is measured by a device which can be moved along the full length of the beam. The transverse profiles of highway pavements are frequently measured with such devices. (These devices should not be confused with two-wheel profilometers, which have the distance measurement device fixed to the center of the beam).

When in use, a physical straightedge rests on the two highest points of the pavement profile beneath the straightedge. This is illustrated in figure 1. ProFAA simulates the operation of the straightedge by setting one end of the straightedge on a specified profile sample and computing the upper convex hull for all of the profile sample points within the full length of the simulated straightedge. The two highest points in the convex hull become the support points of the straightedge, and define a straight line representing the bottom edge of the simulated straightedge. The vertical distance from the straight line representing the straightedge to each of the profile sample points beneath the straightedge is computed. The maximum value of all the vertical distances is reported as the maximum deviation from the straightedge over its full length. A second option allowed in ProFAA, and settable by the user, is to compute and report the maximum deviation from the straightedge between the supports. The length of the straightedge can also be set by the user.
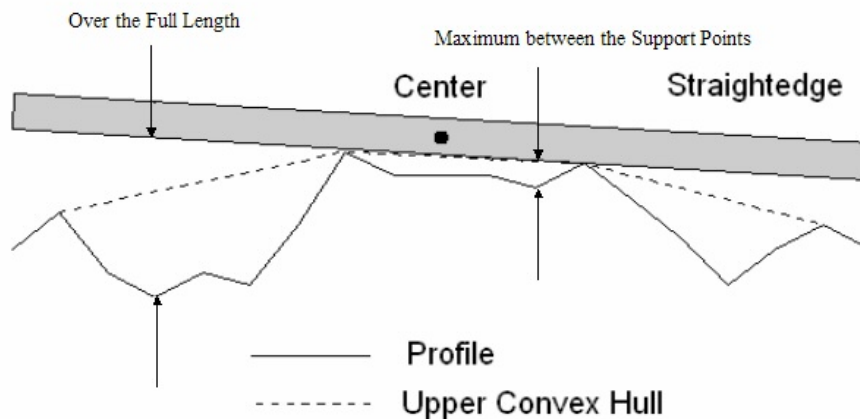

Figure 1. Simulation model of physical straightedge.

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After the maximum deviation has been found for the first straightedge position along the profile, the reference end of the straightedge is moved one sample point along the profile. The maximum deviation is found and the procedure repeated until the specified index length has been covered. All of the reported maximum deviations are then averaged and the average value returned as the index value over the specified index length.

Important considerations in any computer simulation model used to calculate roughness indexes are the profile sample spacing and any processing which might be done to the samples before computing the index. In the FAA system, the 25-mm spaced samples are low-pass filtered and subsampled to 150 mm (5.9 inches) before computing the straightedge indexes.

Four different combinations of straightedge length and deviation measurement length are specified for airport pavement evaluation. The FAA specifies different straightedge lengths for asphalt and concrete surfaced pavements, with deviation measured over the full length in both cases. (The full length requirement is not explicitly stated in the advisory circular, but is the position officially held in response to requests for clarification.) U.S. military specifications have the same length straightedge for both surface types, but deviation between the supports is specified for asphalt surfaces and full length is specified for concrete. The International Civil Aviation Organization (ICAO) is consistent on both surface types, requiring a straightedge 3 m (9.8 ft) long and that deviation be measured over the full length on both surface types. Table 1 summarizes the straightedge requirements specified by the three organizations.

Table 1. Requirements for airport pavement straightedge measurements

	FAA	ICAO	USACE
Length for asphalt	12 ft	3 m	12 ft
Full / Between	Full	Full	Between
Length for concrete	16 ft	3 m	12 ft
Full / Between	Full	Full	Full
Reference	AC 150/5370-10B	ICAO Annex 14	UFGS-02749 UFGS-02753 UFGS-02751N

Computer simulation of the rolling straightedge is preferred over computer simulation of the physical straightedge because the programming is easier and index values are more rapidly calculated. One end of the straightedge is set on a specified profile point and the other end of the straightedge is set on a corresponding profile sample point, as shown in figure 2. These two points then define the straight line defining the simulated straightedge. The maximum deviation of the interior profile points from the straight line is found and reported as the maximum deviation. Index values are found by moving the straightedge along the profile and averaging as for the physical straightedge.
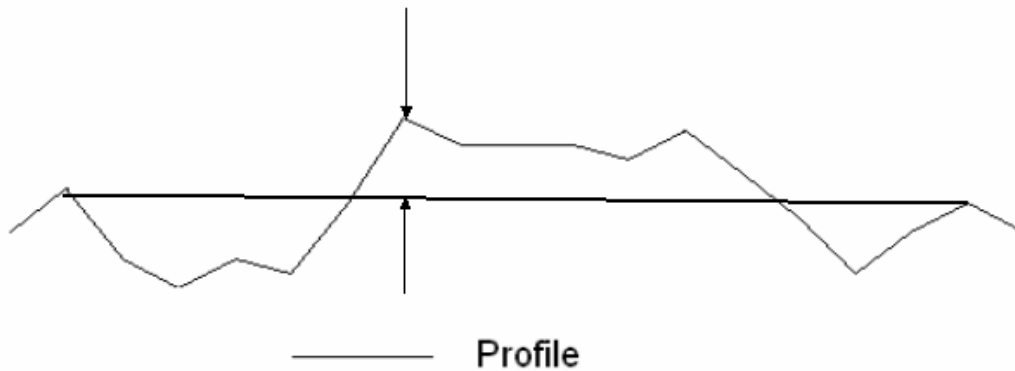
Figure 2. Simulation model of rolling straightedge.

Comparison of Straightedge Indexes

Whether making measurements with physical straightedges or simulating the measurements in a computer program, it would be expected that the results of the measurements would vary with the following factors:

- Type of straightedge
- Length of straightedge
- Deviation measurement length (full or between the supports)

Making physical measurements for a comprehensive comparison of the effects of the indicated factors would be an extremely time consuming and error prone process. But if a comprehensive set of pavement profiles have been measured and stored, it becomes possible to make rapid and repeatable estimates of the effects of the factors. The FAA profiler was used to measure profiles at twelve U.S. commercial airports and four large foreign international airports. The U.S. airports consisted of four large hubs, three medium hubs, and five feeders. The pavement condition at the airports covered the full range of brand new, untrafficked, to being close to the end of functional life. At least one runway and one taxiway was measured at each airport. Multiple runways and/or taxiways were measured at an airport if possible and measurements were usually made in both directions. Repeat measurements were made at some of the airports at intervals of one or two years. The total number of profiles available for analysis is therefore much greater than the number of airports visited. For analysis, the pavements measured were divided into asphalt and concrete surface types and into taxiways and runways. The method of analysis was to compute the index values over the full length of the measured profiles and to make scatter plots of the data to determine linear correlations between the different indexes. All linear correlation equations were constrained to pass through the origin.

Figure 3 compares different straightedge lengths for asphalt taxiways, with the FAA asphalt standard 12 ft straightedge as the reference length. Figure 4 compares different straightedge lengths for concrete taxiways, with the FAA concrete standard

16 ft straightedge as the reference length. The correlation coefficients are very good for all of the data sets and the charts confirm that the length of the straightedge has a very significant effect on the computed index. For example, a 16-ft straightedge measurement is 30 percent larger than a 12-ft straightedge measurement, whereas a 9.8-ft straightedge measurement is 14 percent smaller than a 12-ft straightedge measurement. Rearranging figure 4 to make the 12-ft straightedge the reference gives figure 5, where it can be seen that the two completely different data sets give almost the same correlation equations. (The runway data sets give very similar results but correlation equations have not yet been generated for all of the data points combined.)
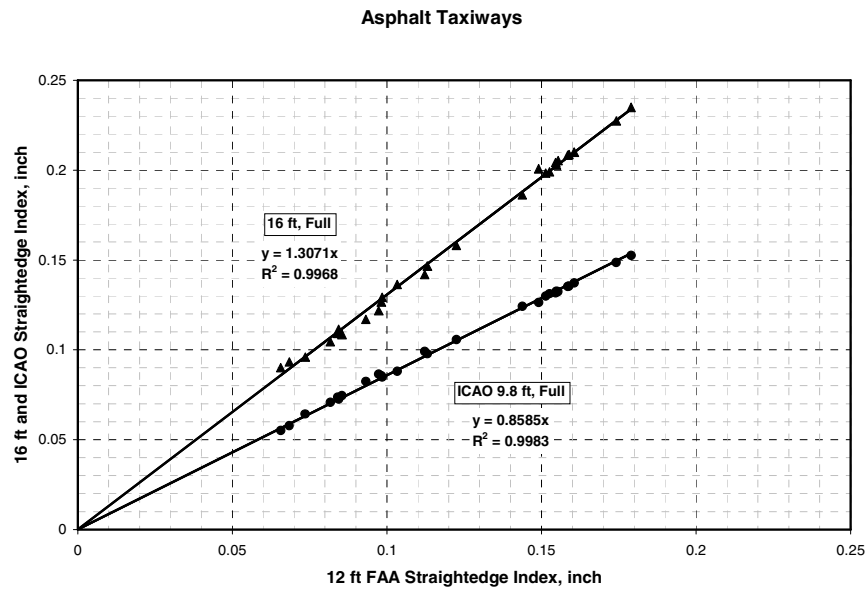
Asphalt Taxiways

Figure 3. Straightedge indexes for asphalt taxiways, 12-ft reference.
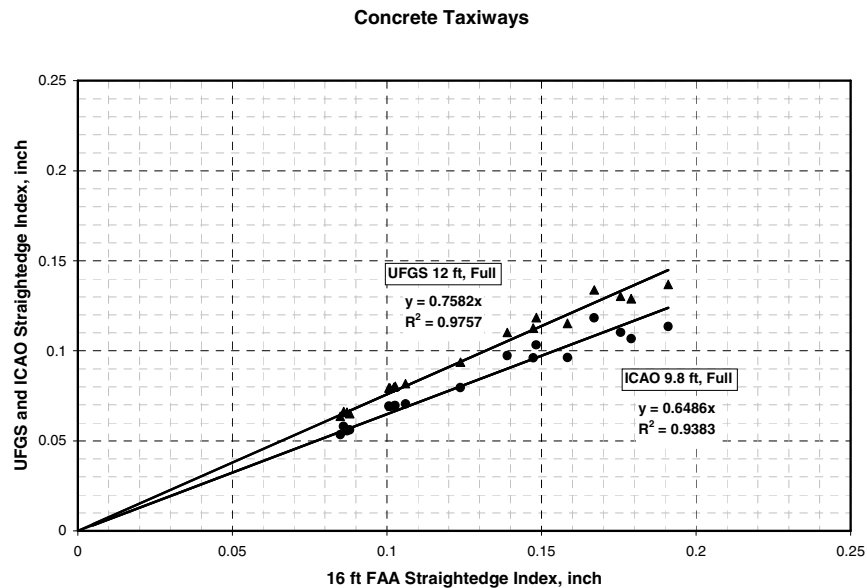
Concrete Taxiways

Figure 4. Straightedge indexes for concrete taxiways, 16-ft reference.
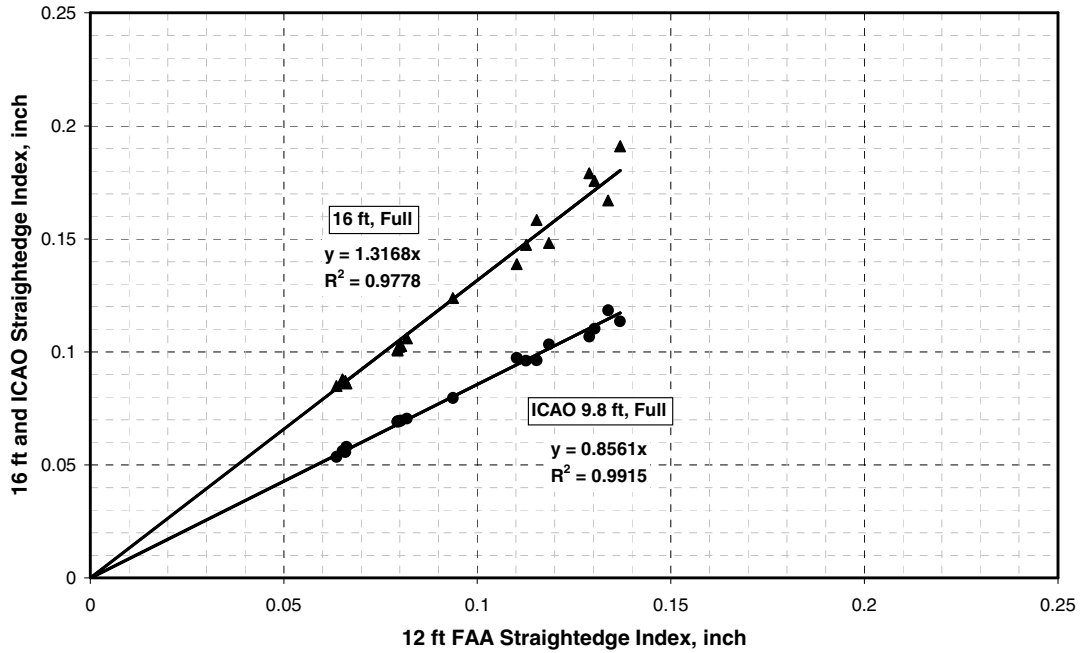
Concrete Taxiways

Figure 5. Straightedge indexes for concrete taxiways, 12-ft reference.

Plotting the slopes of the correlation equations from figures 3 and 5 against straightedge length, and assigning a slope of one for a straightedge length of 12 ft, gives figure 6. This figure can be used to generate a straightedge index conversion factor for any length of straightedge relative to a 12-ft FAA straightedge index measurement.
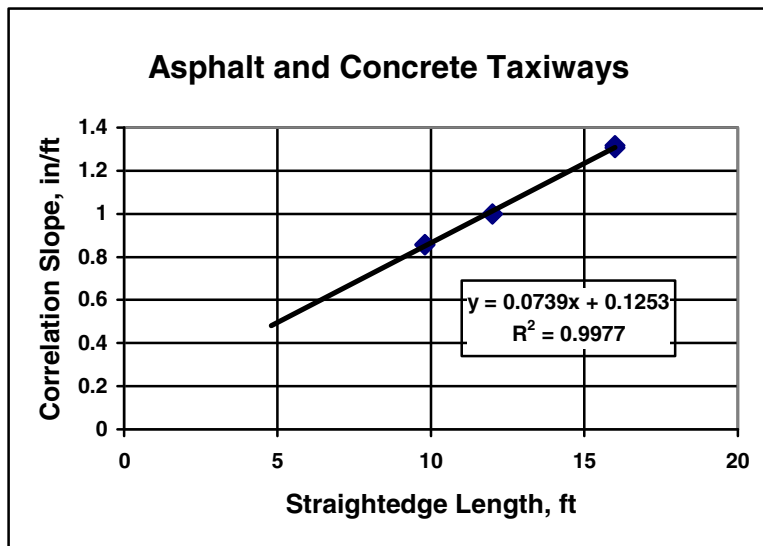

Figure 6. Correlation equation slope as a function of straightedge length.

Figures 7 and 8 compare different measurement types for asphalt and concrete runways. Both figures demonstrate that measuring maximum deviation between the supports gives index values approximately 65 percent of those determined by measuring maximum deviation over the full length of the straightedge. When the indexes are computed using a rolling straightedge simulation, the index values are even lower at about 40 percent of the full length maximum deviation measurement method. The correlation coefficient (R^2) for the rolling straightedge correlation on asphalt runways is also quite low at 0.553. It is not known why this should be so. The correlation coefficient for the rolling straightedge on concrete runways is also significantly lower than the physical straightedge simulation correlation coefficients.
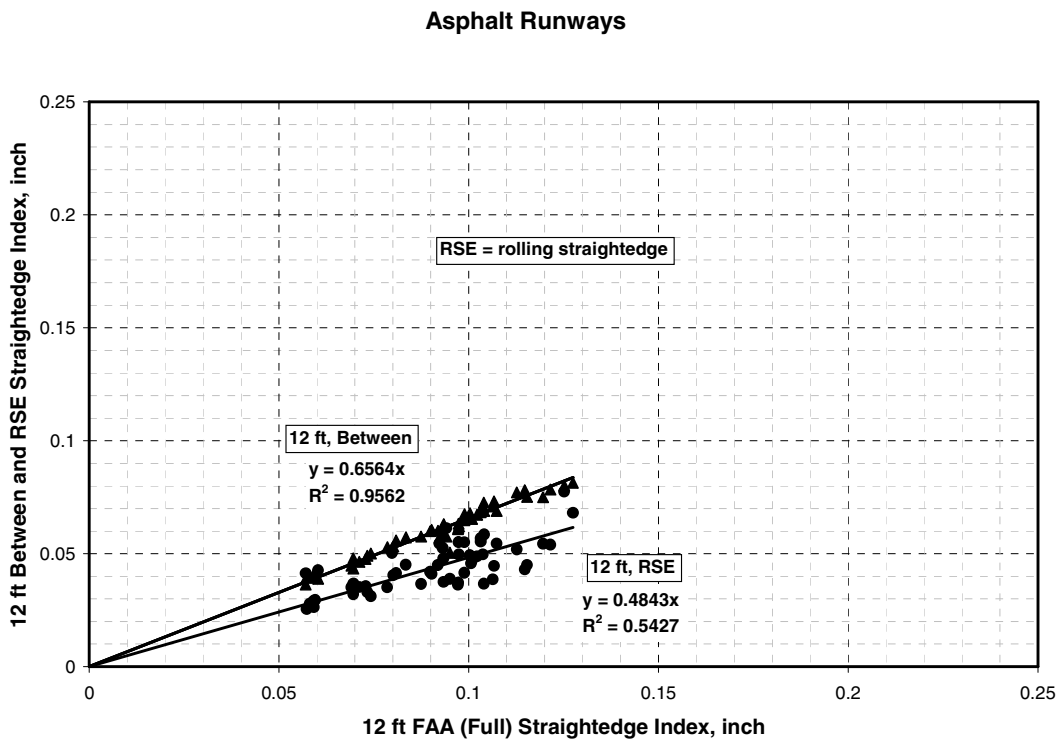
Asphalt Runways

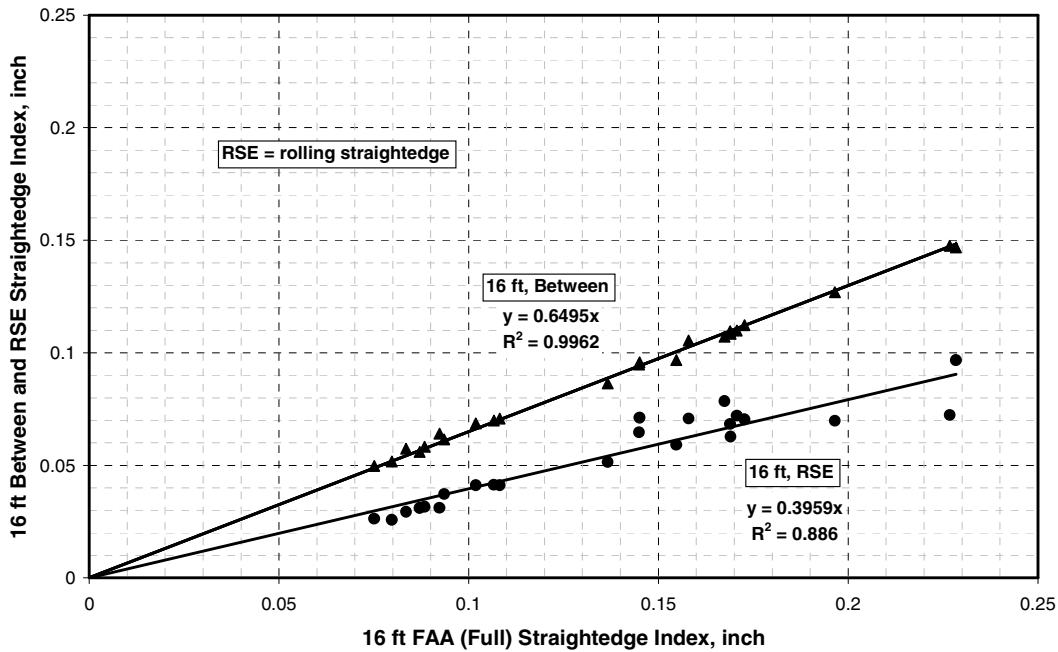Figure 7. Straightedge indexes for asphalt runways, 12-ft reference.

Concrete Runways

Figure 8. Straightedge indexes for concrete runways, 16-ft reference.

Rolling Straightedge Versus FAA Specification Straightedge on Concrete Pavements

A strong candidate for adoption as a standard for smoothness evaluation of concrete airport pavements from automatic profile measurements (Gerardi et al., 2006) is the rolling straightedge as defined earlier in this paper. Candidate lengths are 16- and 25-ft. Correlations were therefore run to determine the relationships between rolling straightedge index calculations and FAA specification straightedge calculations (16-ft long with maximum deviation over the full length of the straightedge) for concrete runways and taxiways. The data sets were the same as those presented in the previous section and the calculation procedures were also the same. The taxiway measurements were from five airports and the runway measurements were from seven airports. Figure 9 shows the results for concrete taxiways and figure 10 shows the results for concrete runways. In all cases the rolling straightedge gave significantly lower index values than the FAA specification straightedge. The 16-ft rolling straightedge gave better correlation coefficients than the 25-ft straightedge, which is to be expected because the FAA straightedge is also 16 feet long. Nevertheless, the rolling straightedge to FAA straightedge correlation coefficients are all significantly lower than the normal to normal straightedge correlation coefficients obtained in the previous section.
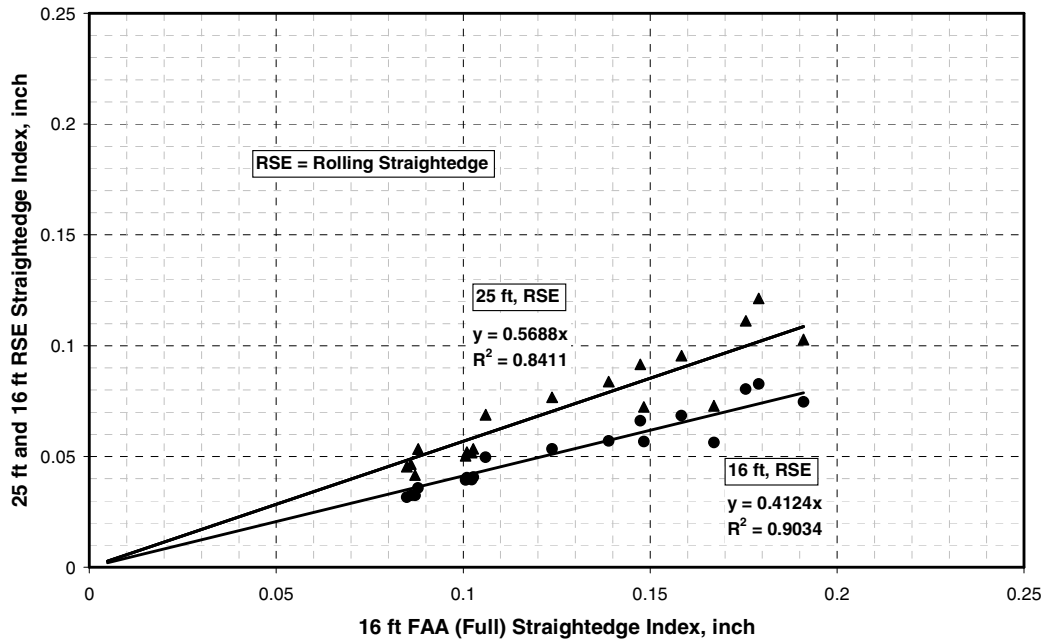
Concrete Taxiways

Figure 9. Rolling straightedge versus FAA specification straightedge for concrete taxiways.
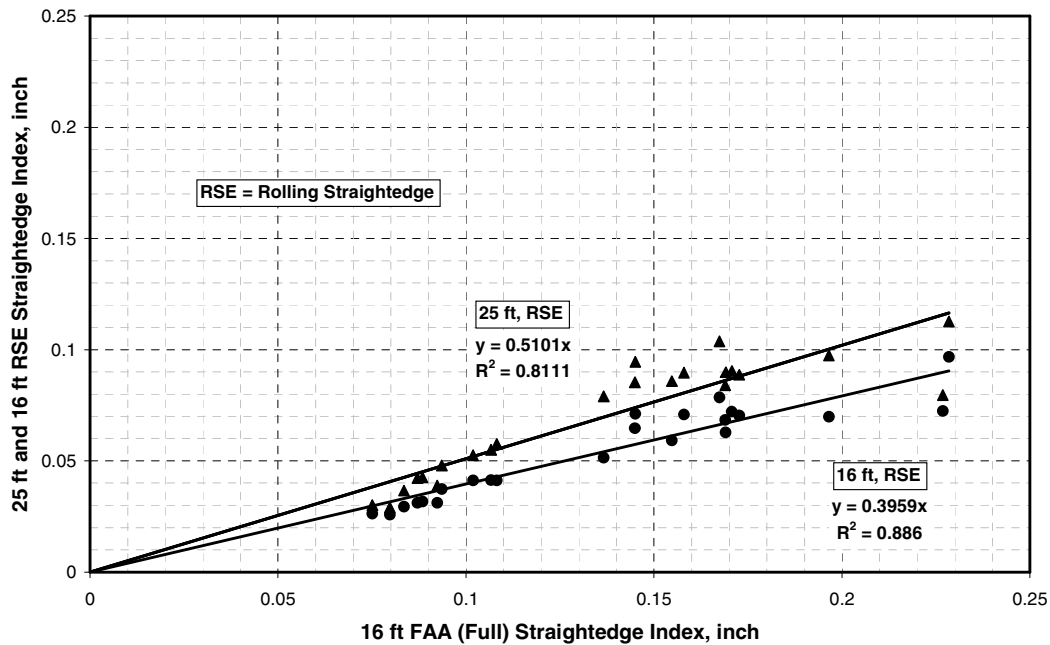
Concrete Runways

Figure 10. Rolling straightedge versus FAA specification straightedge for concrete runways.

Conclusions

Measurements of airport pavement longitudinal elevation profiles made at sixteen airports with an inertial profiling device were used to compute straightedge index values. The index values were calculated using computer simulations of two types of straightedges, four different straightedge lengths, and two different procedures for finding the maximum profile deviations from the straightedge. Reliable relationships between the index values for different straightedge configurations have been developed. This allows specifications for different straightedges to be compared quantitatively. The relationships between rolling and normal straightedge indexes are somewhat less reliable than between different configurations of normal straightedges, indicating that the rolling straightedge has somewhat different evaluation characteristics than the normal straightedges.

Acknowledgement/Disclaimer

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