U.S. Department of Transportation

Federal Aviation Administration

Advisory Circular

Subject: Guidelines And Procedures For Measuring Airfield Pavement Roughness	**Date:** **DRAFT** **Initiated by:** AAS-100	**AC No:** 150/5380-9 **Change:**

1. PURPOSE. This Advisory Circular (AC) provides guidelines and procedures for measuring and evaluating runway roughness as measured by surface profile data of rigid and flexible airport pavements.

2. CANCELLATION. N/A.

3. APPLICATION. The FAA recommends the guidelines and standards in this AC for evaluation of airport pavement roughness. In general, this AC is not mandatory and does not constitute a regulation. However, use of these guidelines is mandatory for new construction or rehabilitation work funded under Federal grant assistance programs. **It also provides one, but not the only, acceptable means of meeting the requirements of Title 14 Code of Federal Regulations (CFR) Part 139, Certification of Airports for measuring airfield pavement roughness.** Mandatory terms such as "must" used herein apply only to those who perform activities using Airport Improvement Program (AIP) or Passenger Facility Charge Program (PFC) funds, or those who seek to demonstrate compliance by use of the specific method described by this AC.

a. PRINCIPAL CHANGES. This is a new AC.

4. RELATED READING MATERIAL. The publications in Appendix 3, Bibliography, provide further guidance and technical information.

5. METRIC UNITS. To promote consistency with ICAO guidance, the text and figures include both metric and English dimensions. Dimensions are provided in metric units and the conversion to English units is based on operational significance and may not be exact equivalents.

6. COMMENTS OR SUGGESTIONS for improvements to this AC should be sent to:

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7. COPIES OF THIS AC. The Office of Airport Safety and Standards is in the process of making ACs available to the public through the Internet. These ACs are available through the FAA home page (www.faa.gov). A printed copy of this AC and other ACs can be ordered from the U.S. Department of

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CHAPTER 1. INTRODUCTION TO AIRPORT PAVEMENT ROUGHNESS

1.1 PURPOSE OF ADVISORY CIRCULAR. The guidance in this advisory circular provides airport operators with procedures to evaluate a pavement surface profile with regards to roughness and the impact pavement roughness may have on civilian airplanes.

1.2 BACKGROUND OF ADVISORY CIRCULAR.

a. Pavement Surface Irregularities. Airport pavement surfaces must be free of irregularities which can impair safe operations, cause damage, or increase structural fatigue to an airplane. Engineers refer to these surface irregularities as pavement roughness or lack of smoothness. Due to large differences in airplane size and performance, the aviation industry has struggled with exactly how to quantify roughness in terms that have meaning to airplane operations. The guidance in this AC provides technical procedures to quantify surface irregularities and to determine how surface irregularities may affect specific categories of airplanes.

b. Airfield versus Highway Roughness. The highway industry defines pavement smoothness/roughness in terms of the ride quality experienced by a passenger. Automotive manufacturers design suspension systems to reduce the impact of common surface irregularities and improve overall ride quality. In contrast, the primary purpose of an airplane suspension system is to absorb energy expended during landing. Airplane suspension systems have less capacity to dampen the impact of surface irregularities due to the magnitude of the energy that must be addressed during landing,

c. Categories of Airfield Pavement Roughness. The FAA groups airfield pavement roughness into two categories based upon the dimensions and frequency of surface deviations:

1) Single Event Bump. Single event bumps are isolated events where changes in pavement elevation occur over a relatively short distance of 100 meters or less. Such elevation changes may occur as an abrupt vertical lip or as a more gradual deviation from a planned pavement profile. Depending upon operational speed and bump length an airplane suspension system may not be able to fully react to absorb the energy associated with an event. Airplane components and occupants feel the impact as a shock or sudden jolt. Basic “straightedge” analysis can easily identify single event bumps. It is possible to observe shorter length bumps by riding the pavement in common passenger vehicle; however, longer length bumps may not be obvious without conducting a thorough analysis of the pavement profile.

2) Profile Roughness. The FAA defines profile roughness as surface profile deviations present over a portion of the runway which cause airplanes to respond in a manner that may increase fatigue on airplane components, reduce braking action, impair cockpit operations, or cause discomfort to cabin occupants. Response is dependent upon airplane size, weight, and operation speed. Roughness may or may not cause discomfort to passengers but may still affect the fatigue life of airplane components or decrease operational safety of the airplane. Depending upon airplane characteristics and operating speed, an airplane may be excited into harmonic resonance due to profile roughness which can cause increases in inertial forces or vibrations within the airplane structure. . One example is resonant response in a 4-wheel truck pitch mode, inducing elevated friction in the pivot joint. Driving a pavement in a common passenger vehicle may or may not identify profile roughness.

d. Passenger Comfort. There are many elements to address when defining pavement roughness experienced by an airplane. A common misconception is that airport pavement roughness is defined by perceived ride quality or passenger discomfort. Although important, passenger discomfort due to pavement surface irregularities is often not a significant issue since the degree of discomfort is small and the time of exposure is limited to a few seconds. Passenger discomfort is often limited to takeoff and landing operations when engine noise, aerodynamic noise, and/or horizontal acceleration or deceleration otherwise distract the passengers.

e. Factor Affecting Safe Airplane Operations. Stress on airplane components, reduced braking action, and the ability to view cockpit instrumentation are areas of concern related to safe operation of the airplane. Pavement surface irregularities may cause vibrations in the cockpit such that pilots cannot focus on critical instrumentation or may have difficulty manipulating the controls during takeoff or landing. Pavement surface irregularities may also cause increased stress levels on critical airplane components which increase the risk of premature failure. Airplane response to surface irregularities can reduce braking capacity as the airplane responds to vertical acceleration. These activities may occur individually or in combination depending upon airplane response.

f. Pilot Response and Feedback. Pilot observations and complaints are an important factor in determining pavement roughness. Although pilot observations do not directly indicate that structural fatigue of airplane components is occurring, they are often the first sign that something is wrong with the pavement profile. The procedures in this AC use pilot observations to establish basic criteria for evaluation of pavement roughness.

g. Surface Texture. Do not confuse pavement roughness as discussed in this Advisory Circular with pavement texture. Pavement texture is the micro texture of the immediate pavement surface which contributes to friction between the airplane wheel and the pavement surface. Pavement texture and pavement grooving is not a source of roughness. See ASTM E 867-04, Terminology Relating to Vehicle-Pavement Systems, for definitions of texture.

h. Construction Standards. When constructed in accordance with the design standards of AC 150/5300-13, Airport Design, and the construction standards of AC 150/5370-10, Standards for Specifying Construction of Airports; an airfield pavement should not have issues with surface irregularities. However, as a pavement ages, the surface profile may vary from the original design standards due to various factors such as frost heave or subgrade settlement.

CHAPTER 2. CRITERIA FOR EVALUATION OF SINGLE EVENT BUMPS IN RUNWAY PAVEMENT

2.1 INTRODUCTION TO SINGLE EVENT BUMP EVALUATION. Undesirable elevation changes on runway pavements can increase stress on airplane components, create difficulties in reading cockpit instrumentation and/or cause discomfort to passengers. Typically, large wavelength bumps are the most prevalent but are not usually visible to the naked eye. The most critical bump height associated with these large wavelength bumps depends on the relationship between the wavelength and the natural frequency of the aircraft. Single step type bumps, or a vertical deviation with zero length, i.e. a vertical lip or fault in the pavement surface, are rarely a problem in service since the step size is usually within the acceptable range.

This chapter provides guidance on evaluating a pavement surface profile to identify potential single event surface deviations that can affect airplane operations. The guidance, based on fully loaded jet transport airplanes operating at near-rotation speeds (130 to 200 knots), is appropriate for runway applications. The guidance provides conservative results for areas of pavement with slow moving traffic such as taxiways or aprons. The derivation of the guidance is described in Boeing document D6-81746 "Runway Roughness Measurement, Quantification and Application – The Boeing Method" by K. J. Debord. The Boeing document is available from the frequently asked question (FAQ) section of the Boeing website (http://www.boeing.com/commercial/airports). The aviation industry and International Civil Aviation Organization (ICAO) refer to the procedure as the “Boeing Bump” method.

2.2 BOEING BUMP EVENT IDENTIFICATION PROCEDURE.

a. Basic Procedure. The basis of the Boeing Bump method is to construct a virtual straightedge between two points on the longitudinal elevation profile of a runway and measure the deviation from the straightedge to the pavement surface. The procedure reports “bump height” as a maximum deviation (positive or negative) from the straightedge to the pavement surface as illustrated in Figure 2-1. Bump length is the shortest distance from either end of the straightedge to the location where the bump event is measured. The procedure plots bump height and bump length against the acceptance criteria in Figure 2-3 as originally developed by the Boeing Aircraft Company.

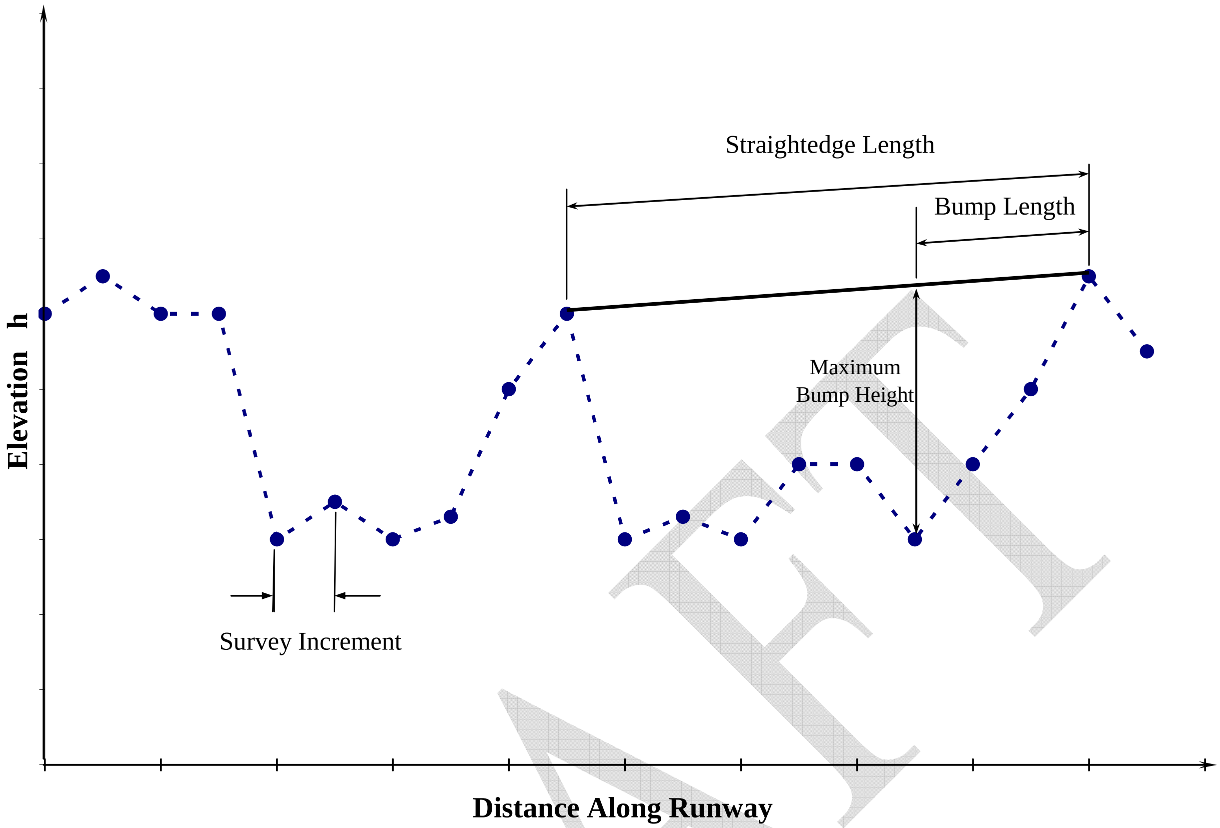

FIGURE 2-1. Schematic of Bump-Height Measurement

b. Maximum Straightedge Length. The Boeing Bump procedure considers straightedge lengths (wavelengths) up to 120 meters (394 feet). Because the Boeing Bump procedure targets isolated bump events, "wavelength" terminology is replace with "bump length". Research sited by Boeing has demonstrated that bump lengths in excess of 120 meters (394 feet) do not contribute to dynamic airplane response.

c. Minimum Straightedge Length. The minimum length of the straightedge is dependent upon the sample spacing or survey interval of the profile data. The minimum length is equal to twice the survey interval. A minimum of three profile data points are required to obtain a deviation from the straightedge as demonstrated in Figure 2-2. Three points are required such that the outer 2 points define the ends of the straightedge and a profile deviation is read at the interior point. The FAA standard for sample spacing is 0.25m for evaluation of the Boeing Bump. Therefore, the minimum straightedge length is 0.5m.

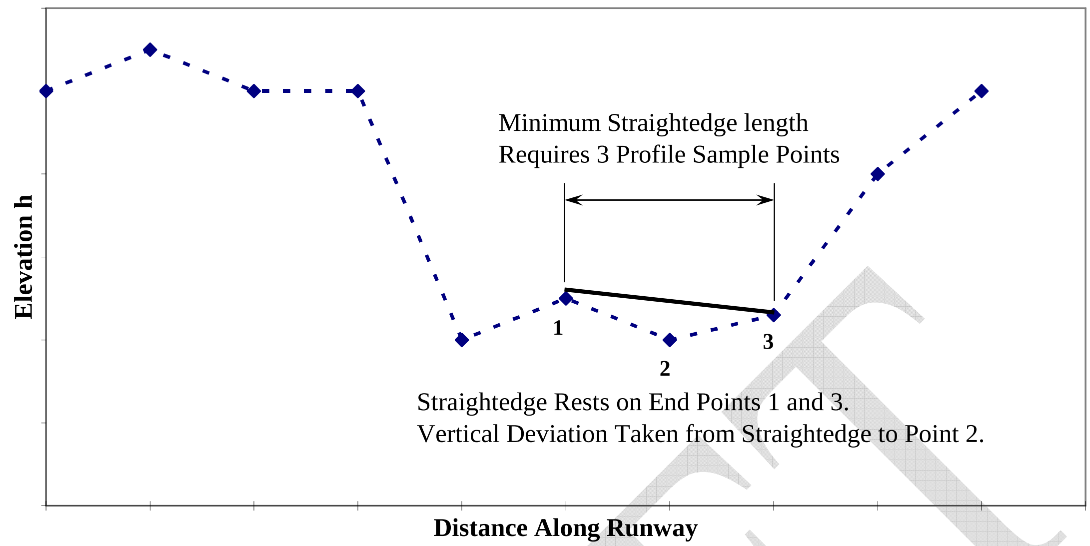

FIGURE 2-2. Minimum Straightedge Determination

d. Number of Straightedges Associated with a Survey Interval. The number of straightedges associated with any survey point is dependent upon the dimension of the survey interval. Each point may have N_s straightedges associated with it, where:

$$N_s = (\text{Maximum Straightedge length} / \text{Survey Interval}) - 1$$

Where:

Maximum Straightedge Length = 120 meters (394 feet)
Survey Interval = 0.25 Meters (0.82 Feet) units consistent with straightedge

For FAA standard configuration:

$$N_s = (120 / 0.25) - 1 = 479$$

At any profile sample point, the procedure allows construction of a straightedge with the beginning of the straightedge at the sample point, with the end of the straightedge at the sample point, or with the sample point at any increment along the length of the straightedge. With each possible straightedge configuration, the procedure calculates "bump height" and "bump length" as defined in paragraphs 2.2d(1) and 2.2d(2) below.

1) Bump Height. Bump height equals the maximum vertical distance from the straightedge to the profile sample point for all positions of the straightedge along the profile. Units are centimeters (inches).

2) Bump Length. Bump length equals the smallest of (a) the distance from the bump height position to the start of the straightedge or (b) the distance from the end of the straightedge to the bump height position. Units are meters (feet).

e. Recommended Survey Interval. The accuracy of the Boeing Bump procedure, or its ability to represent field conditions, increases as the survey interval decreases. Because the accuracy of the procedure changes if the survey interval changes, the FAA requires a survey interval of 0.25 meters (0.82 feet) for evaluation of the Boeing Bump. Chapter 4 describes Profile measuring equipment which includes a wide variety of means and methods of obtaining a surface profile. The FAA recommends using automated profile equipment due to the relatively close survey interval.

f. Recommended Survey Location. Airplane gear location relative to the centerline of a runway vary from airplane to airplane, however, it is not necessary to exactly match location of the airplane gear with the location of the surface profile. The FAA recommends measuring the runway surface profile along the centerline and at a lateral offset (left and right) which approximates the aircraft using the airport. Group II and III airplanes can be effectively address by a 10 foot offset while group IV, V and VI airplanes can be addressed with a 17.5 foot offset. Take measurements at all locations if traffic at a given facility contains all airplane groups. Evaluate each profile in accordance with paragraph 2.3.

g. Use of Inertial Prolilers with Highpass Filtering. Data processing for a typical highway and light-weight inertial profiler includes highpass filtering the accelerometer signal before integration to avoid offset errors. Filtering can have a significant effect on the computation of the BBI and airplane accelerations. Filtering the accelerometer signal instead of the absolute profile is likely to result in a different highpass filtered profile since the accelerometer signal includes bouncing of the profiler vehicle. Inertial profiler filter characteristics are likely to be different between profiler equipment and than those employed by ProFAA. For this reason, the use of inertial profilers that include highpass filtering is not be recommended for measuring profiles which are to be used for computing the BBI of airport pavements, or accelerations from simulated airplanes.

2.3 EVALUATION OF BOEING BUMP PARAMETERS.

a. Bump Evaluation Procedures. Evaluate each combination of bump height and bump length by entering Figure 2-3 with the bump height and length. Figure 2-3 reproduces the criteria presented in figure 10 of Boeing Document D6-81746. This criteria presents pavement roughness associated with a single bump event in terms of Acceptable, Excessive, or Unacceptable. Boeing developed the criteria based upon operational experience for single bump events describing the general condition of a runway pavement. The criterion does not provide a detailed analysis of airplane response nor does it attempt to address the problem of root-mean-square roughness. The criterion also does not address the effects of a series of long wavelength undulation where airplane frequency response is important. By eliminating the root-mean-square and frequency response factors, this simplified criterion can be applied to all jet transport airplanes without regard to structural design or physical characteristics.

b. Evaluation Criteria. The evaluation criterion in Figure 2-3 defines operational conditions and structural impact to the airplane. The follow provides guidance for each evaluation zone.

1) **Acceptable.** The FAA expects newly constructed pavement to result in bump height and length combinations which result in placement within the lower region of the acceptable range. New construction tolerance in Item P-401 and P-501 of AC 150/5370-10 allow 0.25 in (0.64 cm) in 16 feet (4.8 meters) as indicated in Figure 2-3. Operations in this range are acceptable for all airplanes. As a pavement ages, various factors such as frost heave or isolated pavement failures may result in conditions such that the bump height and length combinations approach the limit of the acceptable range.

Experience indicates that pilots begin to report excessive roughness as conditions approach the limits of the acceptable range. When pilot reports begin to occur, airport operators should begin efforts to identify the bump locations and prepare for corrective actions. These actions should include scheduled maintenance activity to monitor the pavement profile.

Whenever roughness is above the acceptable zone, airplane gear fatigue becomes more critical than passenger discomfort or cockpit acceleration limitations. Maximum roughness for passenger comfort and cockpit instrument interference should not exceed the acceptable zone. See paragraph 2.4 for additional guidance on the acceptable zone.

2) **Excessive.** Airport operators are encouraged to repair pavements as roughness levels enter the excessive zone. Airplane response to roughness in the excessive zone becomes noticeably intolerable to both airplane crews and passengers. Roughness of this magnitude will induce acute discomfort to all occupants in the airplane. Instrument interference in the cockpit may be severe. This roughness level also creates conditions where short term loss of airplane steerage is possible as well as excessive reduction in nose and main gear fatigue life. Immediate pavement repairs are necessary but closure of the affected pavement is not required.

3) **Unacceptable.** Roughness levels in the unacceptable zone warrant immediate closure of the affected pavement. Repairs are necessary to restore the pavement to an acceptable level.

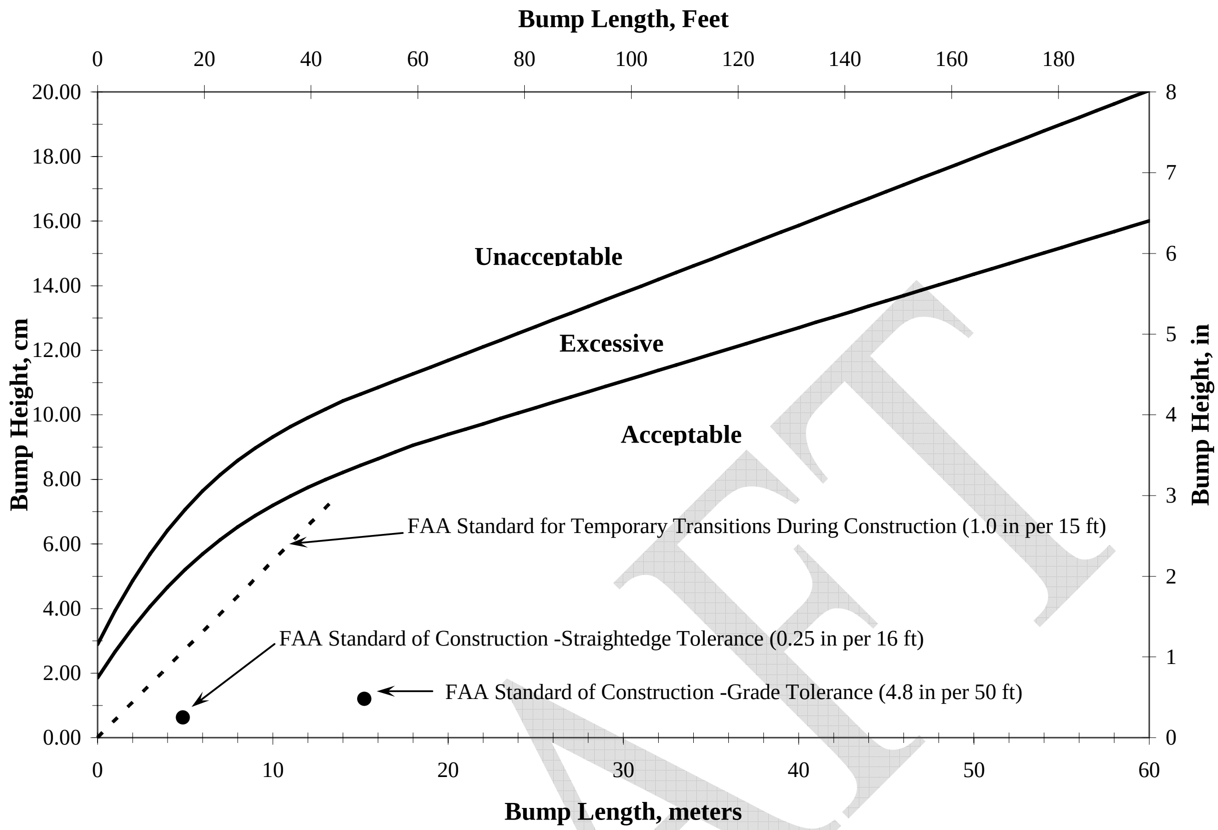

FIGURE 2-3. Single Event Bump - Roughness Acceptance Criteria

2.4 DEVELOPMENT OF THE BOEING BUMP INDEX.

a. Need for Boeing Bump Index. Applying the Boeing Bump method to a pavement profile can be a time consuming and tedious task. Performing a roughness evaluation requires that each point in the profile survey be evaluated for all possible straightedge lengths. For any particular case of runway roughness, both bump height and bump length are significant, particularly when considering strategies for reducing roughness through maintenance. The FAA created an additional parameter for the Boeing Bump procedure in order to summarize the bump criteria and to compare computed bump criteria with other measures of roughness. This new index called the "Boeing Bump Index" (BBI) is defined as follows:

- For a selected sample point in the profile, compute the bump height and bump length for all straightedge lengths.
- For each straightedge length, compute the limit of acceptable bump height (upper limit of the acceptable zone) for the computed bump length.
- For each straightedge length, compute the ratio (measured bump height) / (limit of acceptable bump height).
- The BBI for the selected sample point is the largest of all values computed in step 3 for the selected sample point.
- Repeat steps 1 through 4 for all sample points in the profile.

The computed index value is less than one when roughness is in the acceptable zone and greater than one when the roughness is in the excessive or unacceptable zone.

b. Development of a Software Application for the Boeing Bump Index. In order to implement the procedure for computing the BBI in a computer program, the FAA developed mathematical models of the lower and upper criteria curves as given below:

1) Lower Limit Curve (upper limit of the acceptable zone)

$H = 1.713187 + 0.800872L – 0.031265L^2 + 0.000549L^3$ (for $L \leq 20$ meters)

$H = 6.4 + 0.16L$ (for $20 \leq L \leq 60$ meters)

2) Upper Limit Curve (upper limit of the excessive zone)

$H = 2.747222 + 1.433399L – 0.183730L^2 + 0.013426L^3$ (for $L \leq 5$ meters)

$H = 2.7590 + 1.085822L – 0.053024L^2 + 0.001077L^3$ (for $5 \leq L \leq 20$ meters)

$H = 7.775 + 0.20375L$ (for $20 \leq L \leq 60$ meters)

Where:
H = Bump height (cm)
L = Bump length (meters)

c. Software for Calculation of the Boeing Bump Index. The FAA developed the PROFAA software to aid in the calculation of the BBI. The software is available through the FAA website http://www.faa.gov. Chapter 3 provides additional information on the use of this software.

d. Comparison with Original Boeing Bump Procedure. The Boeing Bump Index procedure varies slightly from the original Boeing Bump procedure because the original procedure was based on manual data processing. The BBI procedure in PROFAA is fully automated and not quite the same as the Boeing Bump procedure in that a maximum or minimum does not necessarily give the maximum BBI for a given profile point. In summary:

- The bump length defined in Boeing document D6-81746, is at a local minimum or maximum. There can be multiple local minima or maxima for a given straightedge length. Presumably the worst combination of bump height and length is the one that governs.

- PROFAA bump length is for the combination which gives the maximum BBI at a profile point, which is not necessarily at a maximum or minimum.

2.5 PAVEMENT ROUGHNESS EVALUATION USING THE BOEING BUMP INDEX.

a. Boeing Bump Index Evaluation Criteria. Evaluation of a pavement profile with the BBI is similar to the evaluation criteria of the Boeing Bump method. Since the BBI is based upon the same three zones of roughness, the recommendations of paragraph 2.3b apply to the corresponding ranges of the BBI. Figure 2-4 express the concepts of Figure 2-3 in terms of BBI versus bump length. Figure 2-4 recreates the acceptable, excessive, and unacceptable evaluation zones of Figure 2-3 in terms of BBI. When the BBI value is below 1.0, the Boeing bump criteria is in the acceptable zone. Values of BBI greater than 1.0 are either in the excessive or unacceptable zone.

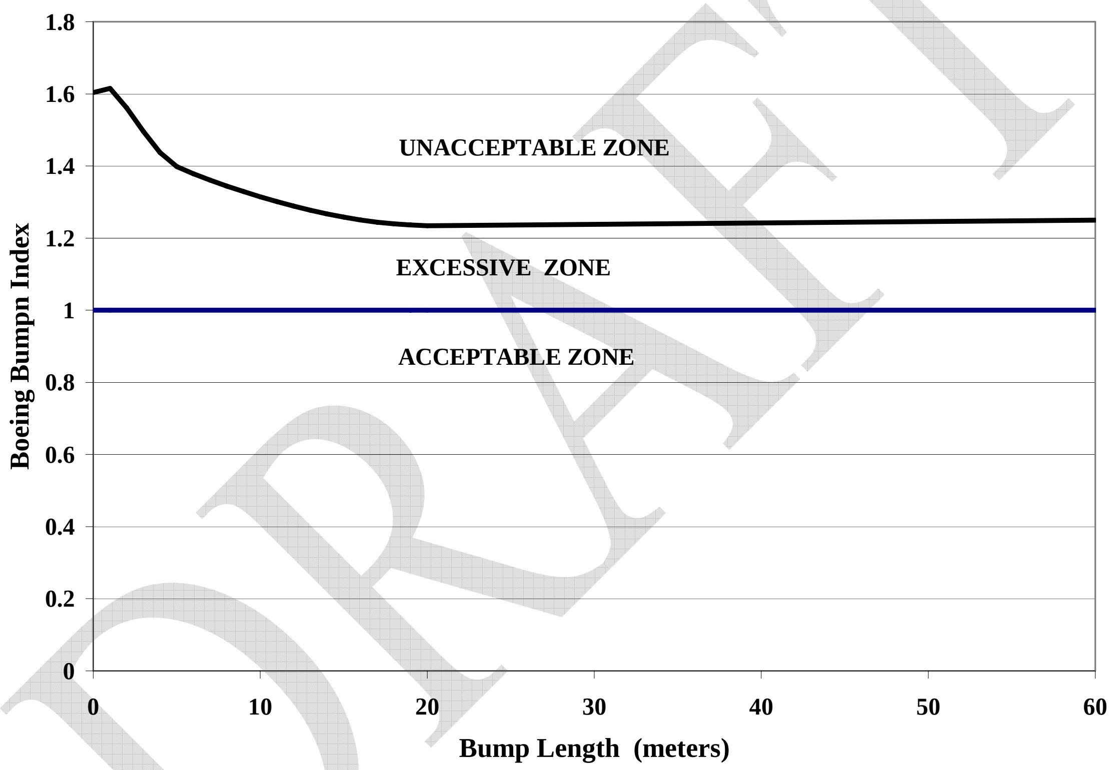

FIGURE 2-4. Boeing Bump Index - Roughness Acceptance Criteria

b. PROFAA Reporting of Boeing Bump Index. The PROFAA software calculates the BBI for all survey intervals in a pavement profile. PROFAA will record each time a profile exceeds the Acceptable and Excessive Zones and output a report indicating each occurrence.

2.6 TEMPORARY PAVEMENT TRANSTIONS REQUIRED DURING CONSTRUCTION.

Airport pavement construction often requires that a pavement be available to airplanes between phases of construction work. This often occurs during off-peak hours with limited construction windows that require multiple phases to complete the pavement. This requirement can create conditions where the pavement surface is not uniform and may require temporary ramps to transition from elevation to elevation. Most often, this condition is associated with construction of Hot-Mix asphalt.

Advisory Circular 150/5370-13, Offpeak Construction of Airport Pavements Using Hot-Mix Asphalt, provides guidance on offpeak construction using Hot-Mix asphalt. This AC recommends a 15-foot ramp for each one inch of elevation change. Figure 2-3 shows how this criterion compares against the upper limit of the acceptable roughness zone. Elevation changes greater than 3-inches will require adjustment of the ramp length to avoid exceeding the upper limit of the acceptable zone.

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CHAPTER 3. PROFAA SOFTWARE

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CHAPTER 4. PROFILE MEASURING EQUIPMENT

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APPENDIX 3. BIBLIOGRAPHY

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2. Report No. FAA-RD-80-55, *Procedures for Condition Survey of Civil Airports,* U.S. Army Engineer Waterways Experimental Station, Vicksburg, MS, May 1980.

3. AC 150/5320-12, *Measurement, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces*.

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