FLIGHT SERVICES

Runway Roughness Evaluation- Boeing Bump Methodology

LIFECYCLE SOLUTIONS

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Outline

- Types of Roughness and Boeing Bump Criteria details
- Profiling Equipment Comparison
- Case Studies done by Boeing
- Standardization of Roughness Criteria
- Conclusions

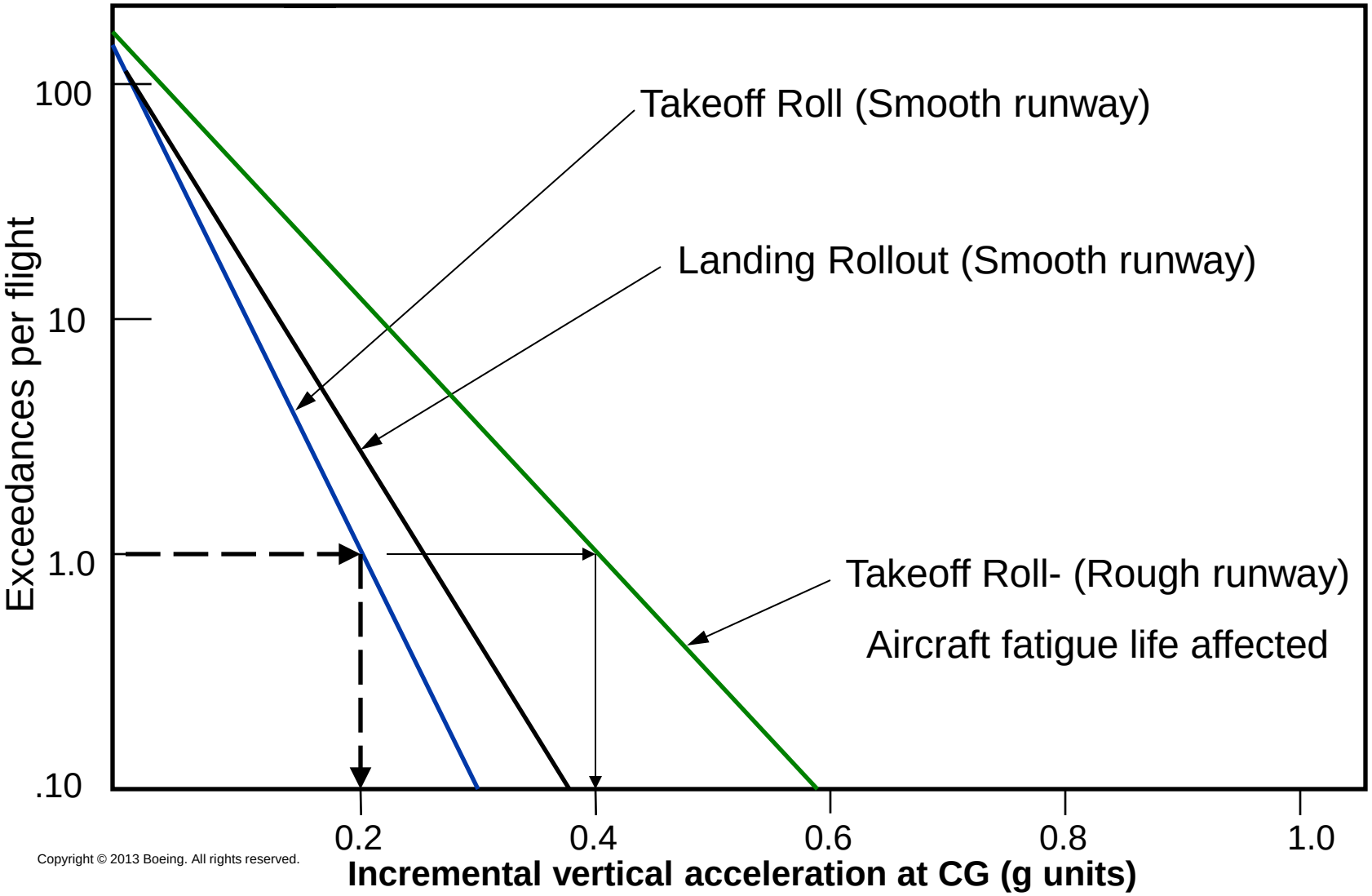
What Type of Roughness is Addressed by the Boeing Bump Criteria

Limit Loads – Single discrete, large wavelength bumps on a runway, which if severe enough, could lead to structural failure by exceeding the limit design loads of an aircraft. Currently, the Boeing Bump Criteria addresses this issue, such that bumps reaching the unacceptable level are repaired.

Two other loading conditions can be addressed by more sophisticated techniques:

1) Fatigue Loads – Continuous large wavelength bumps, which exceed the aircraft design fatigue criteria. This criteria is based on a change in vertical acceleration at the aircraft cg which cannot exceed a once per flight occurrence level.
2) Landing gear truck pivot joint – Continuous short wavelength bumps, which are primarily only an issue in Russia and CIS countries due to poor construction methods for concrete.

Fatigue Life – Exceedance of Airplane Load Factors



Pavement Maintenance Priorities

Runway pavements should fill the following functions:

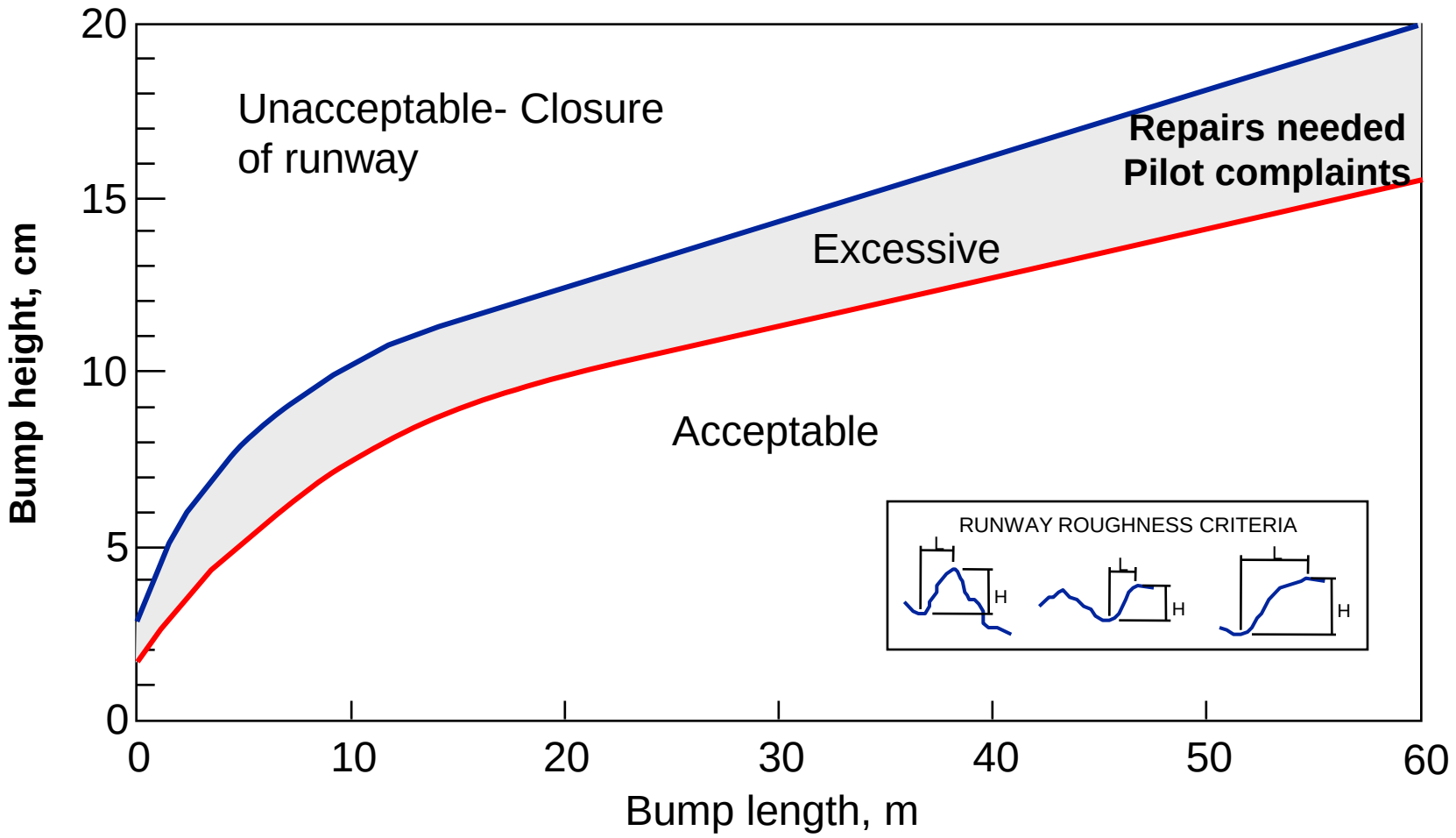
1.) Provide adequate bearing strength- addresses structure of pavement

2.) Provide good ride quality- addresses surface geometrics and runway roughness falls into this function

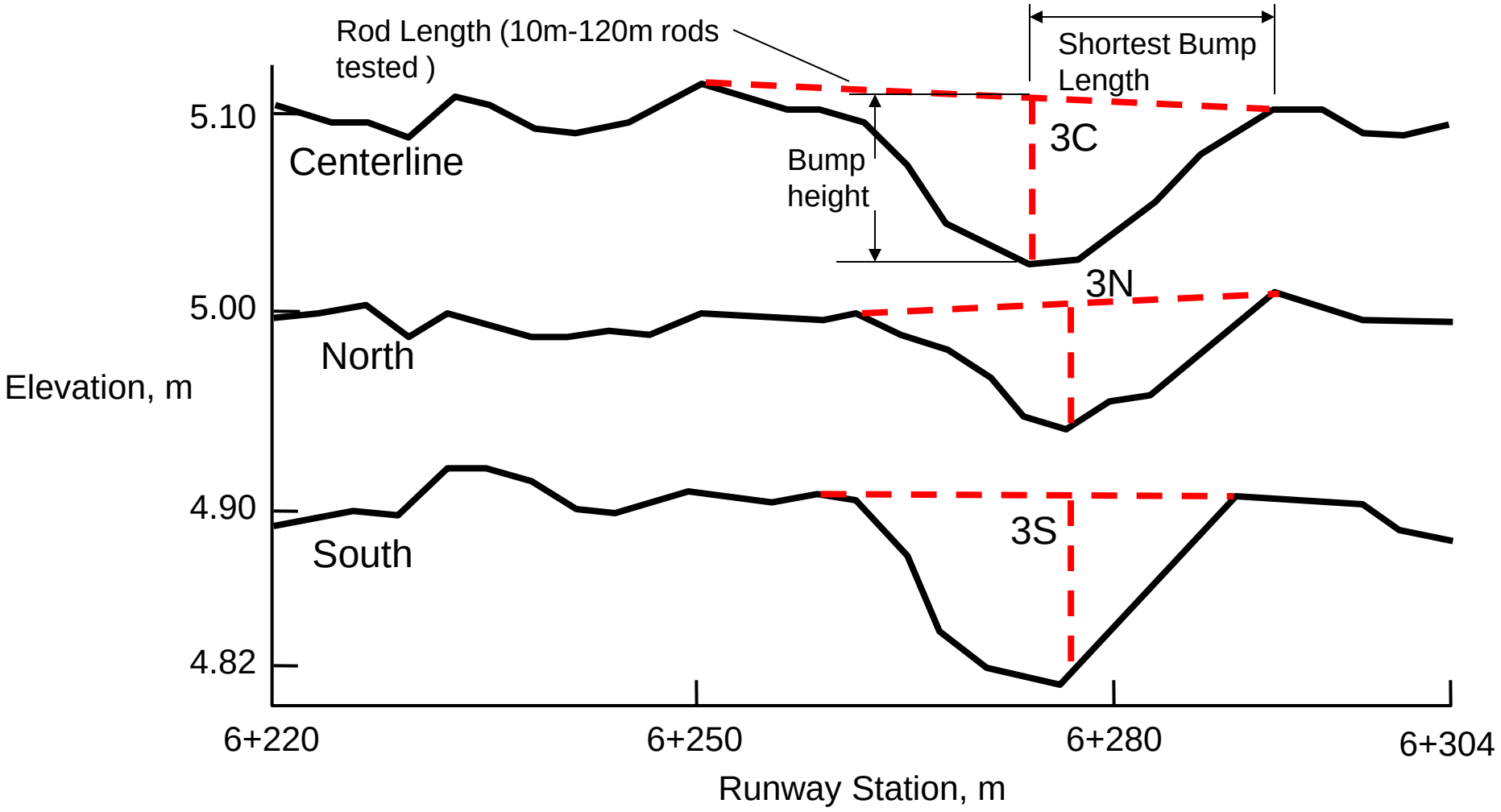
3.) Provide good surface friction characteristics- addresses texture and slope of pavement for adequate drainage

All of these functions are tied to proper pavement maintenance ensuring the pavement is adequate for safe aircraft operations.

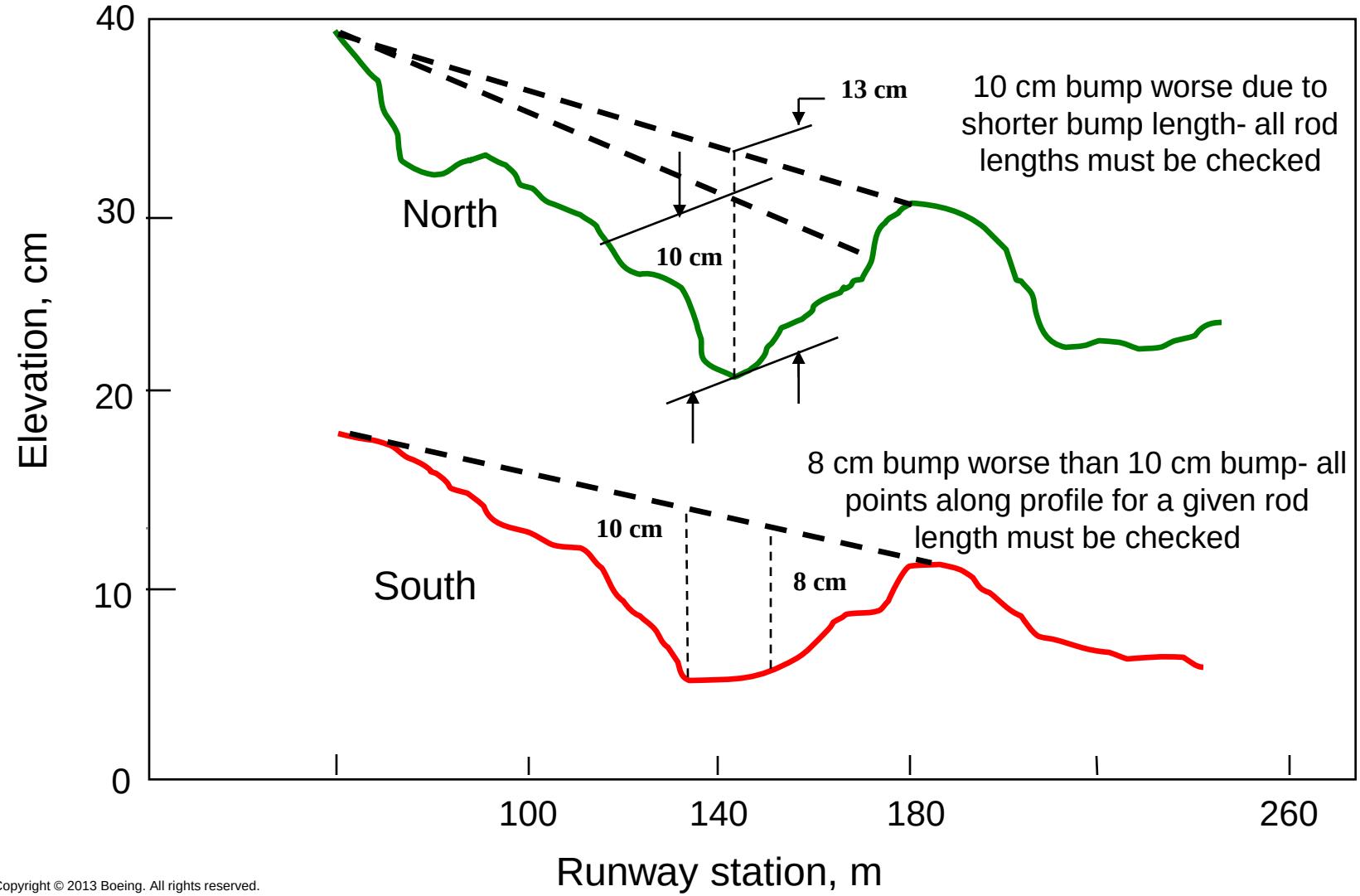
Boeing Runway Roughness Criteria-Single Event Limit Load



Long Wave Depression
Bump Definition



Details of the Boeing Method- Long Wave Depression



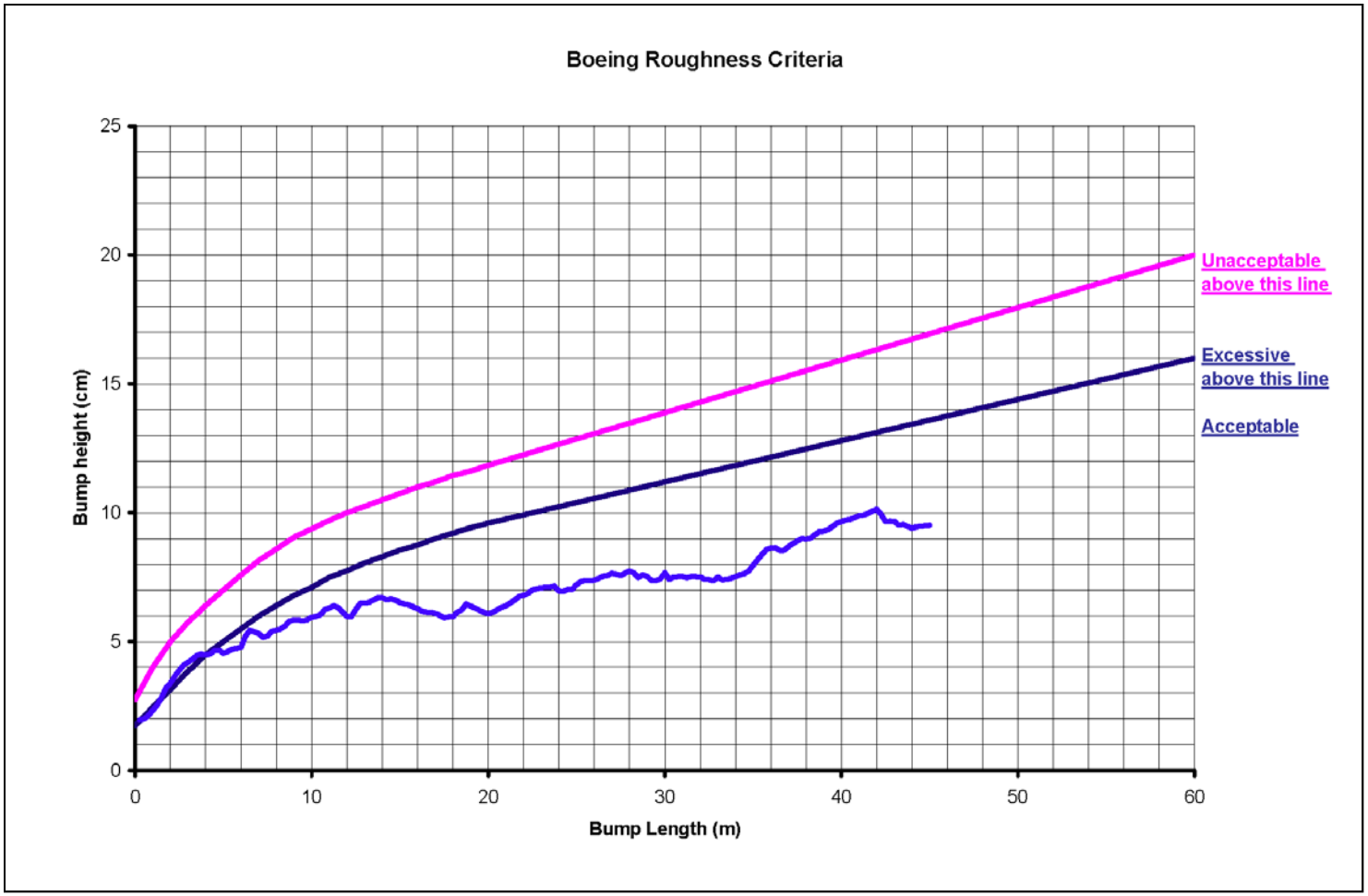
Details of the Boeing Bump Analysis

- Profile smoothing done prior to bump analysis to eliminate raw data roughness not necessarily affecting aircraft. Data is curve fit with smooth spline every 200 meters and correction for slope is done every 100 meters. This flattens profile to better observe roughness.

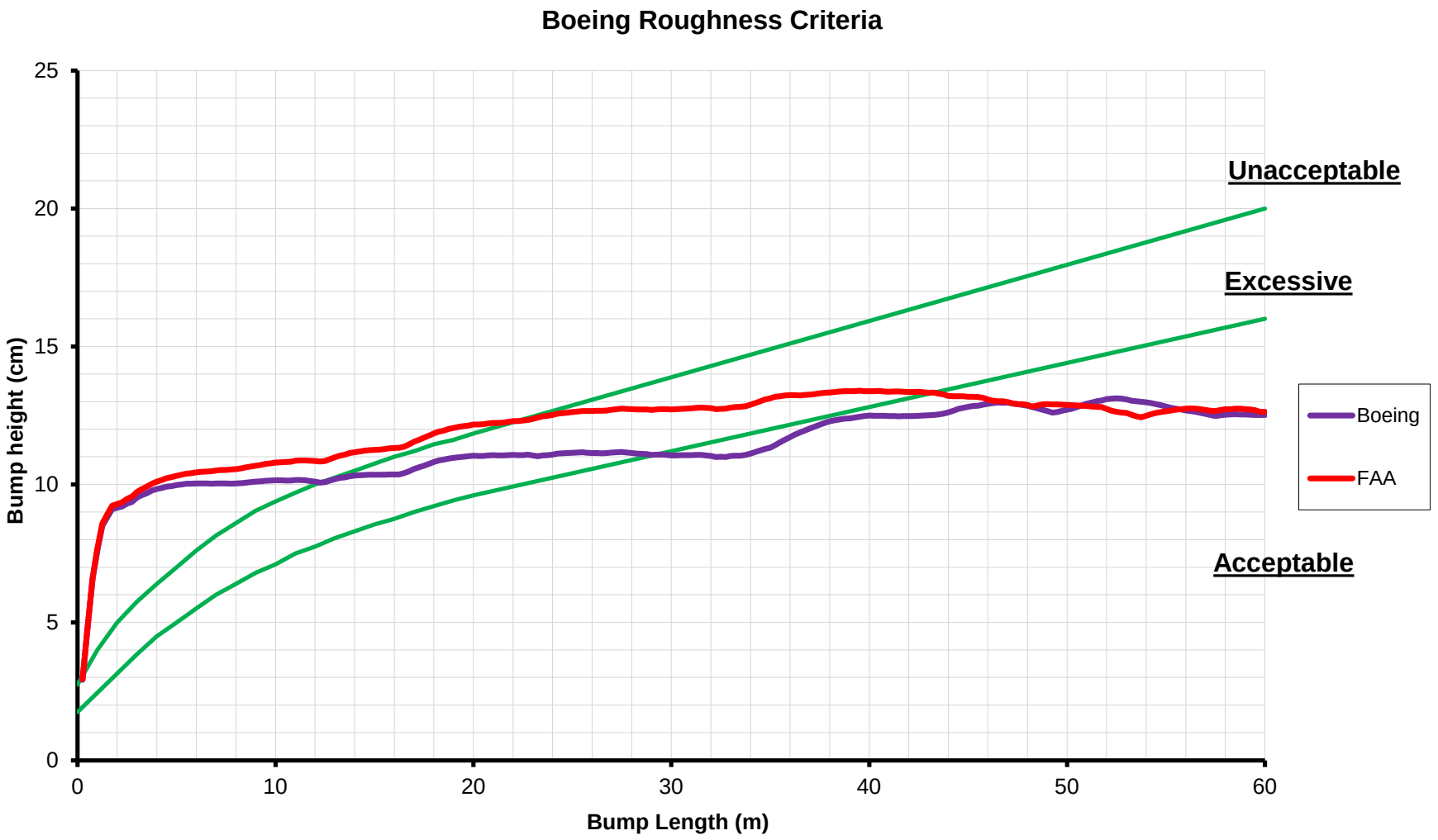
- Rod lengths to be checked start at 5m up to 120 m, increments of 5-10 m typically adequate.

- Plot of worst bumps versus the Boeing criteria indicates areas needing repair. More detailed analysis can be done by plotting 100-200m profile segments.

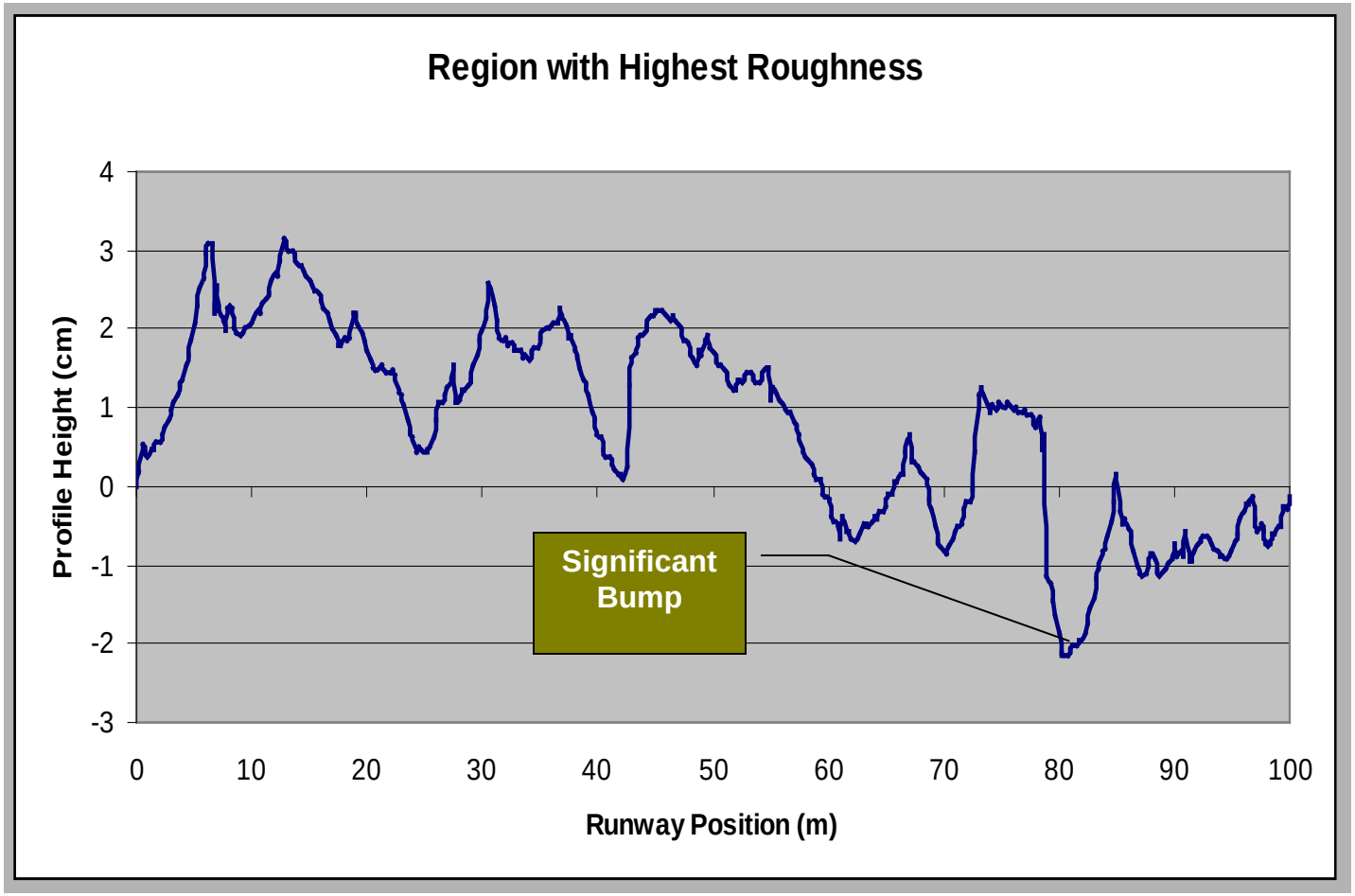
Boeing Bump Analysis- Plot of Worst Bumps



Profile Smoothing Comparison- Boeing vs PROFAA



Boeing Bump Analysis- Detail of Excessive Bumps



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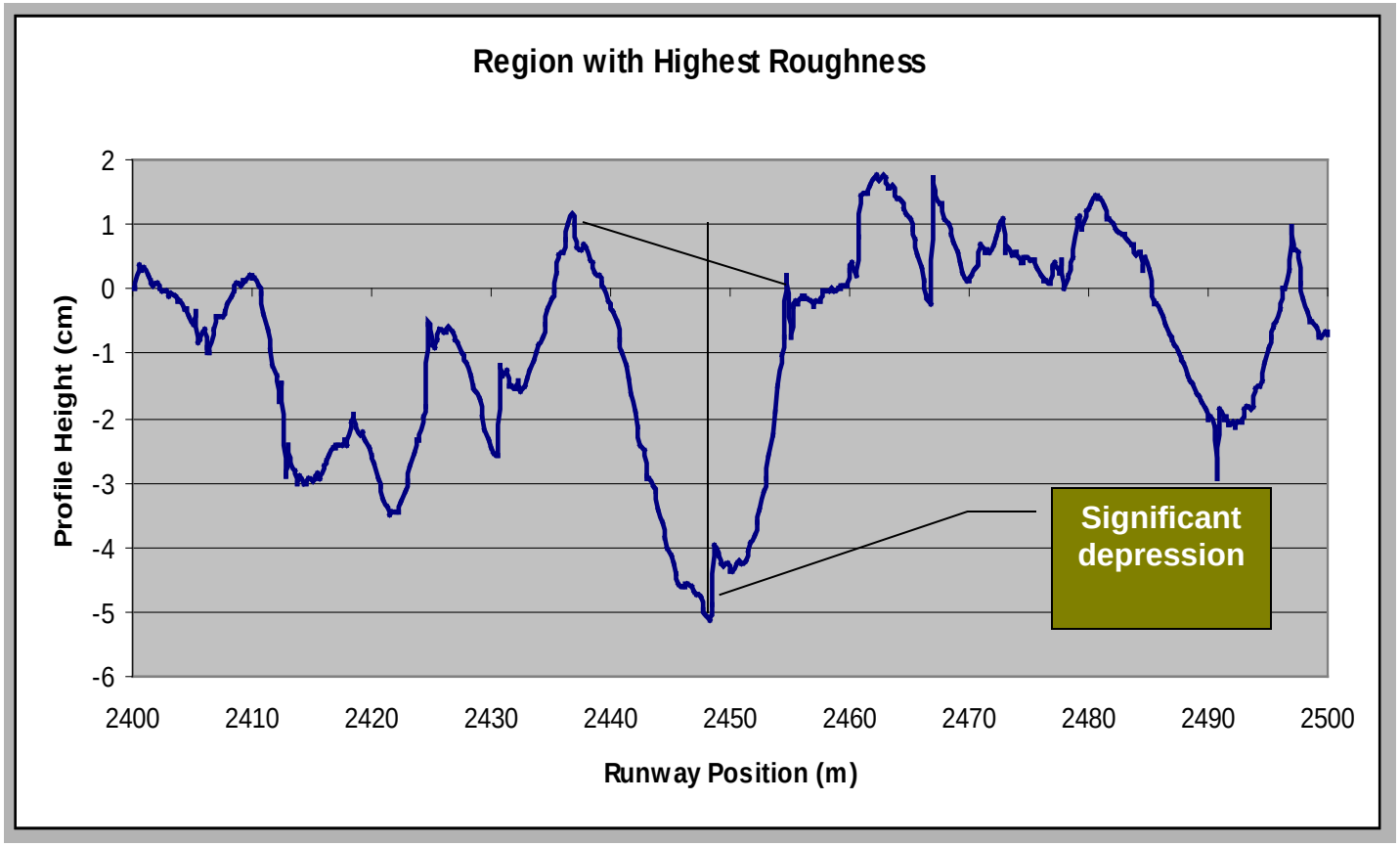
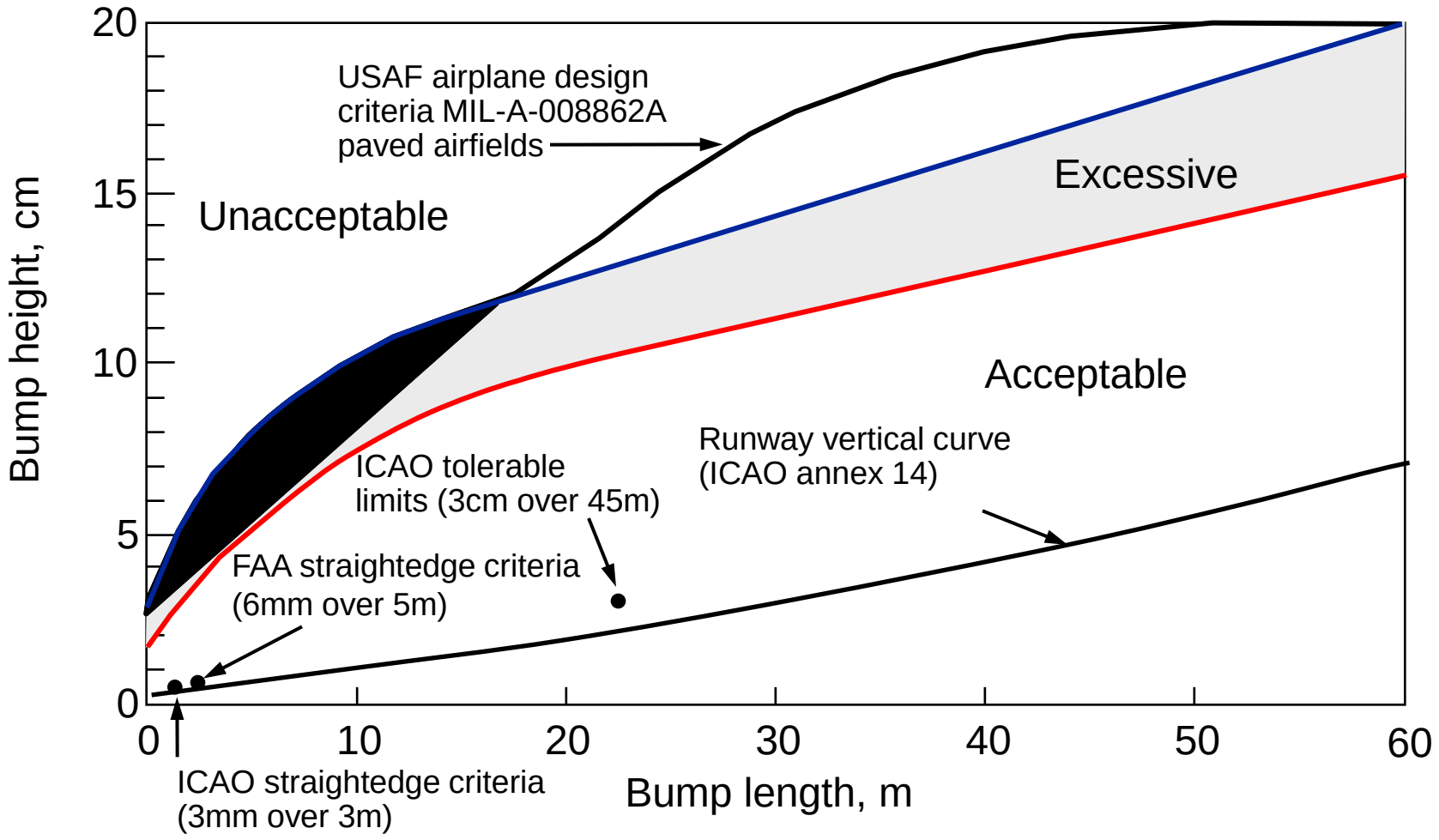


Comparison Between Boeing Criteria and other Criteria



Runway Profiling Equipment Comparison

High Speed Inertial Laser profiler

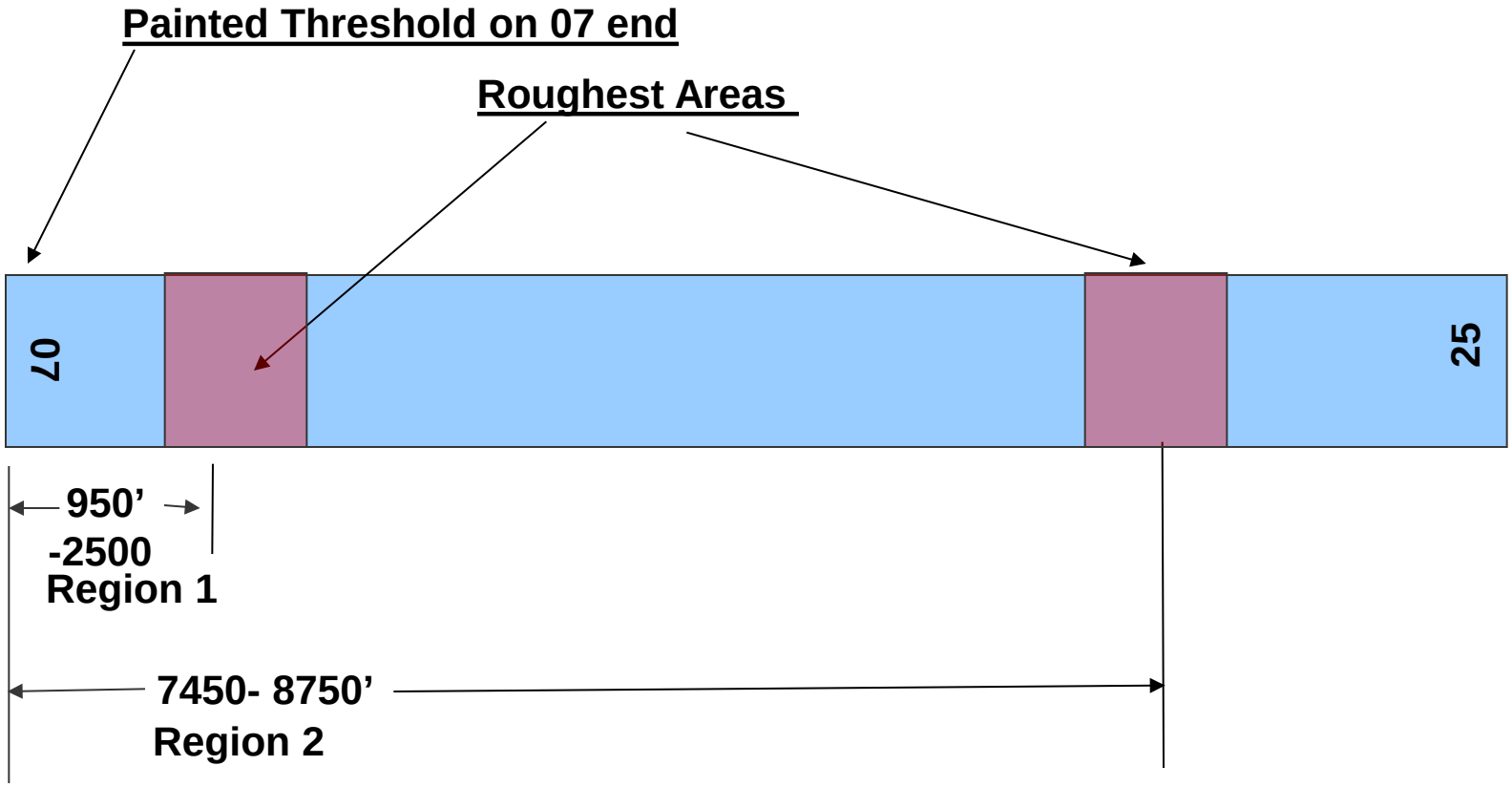
Manual rolling inclinometer profiler

Manual rod and level device

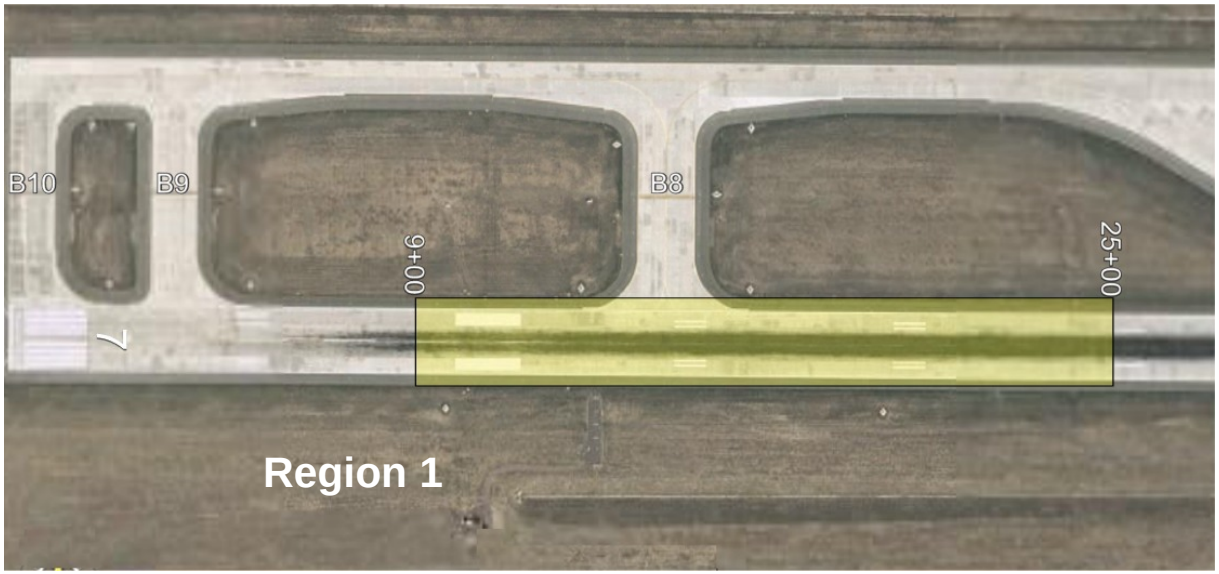
Pavement Assessment Process

- Compare profiles from 3 profiling devices
- Verify that regions of roughness are similar in magnitude for all profilers
- Compare 2 Lines of Survey (CL and 15 Feet Left of CL)
- Roughness determined using Boeing Bump Criteria
- Initial consultant request to review runway 07/25 came to Boeing in 2007. Main concern was fatigue, primarily region 1 dual bump exceeding the once per flight fatigue limit.

Areas of Roughness from APR survey- 2006



Areas of Roughness from APR survey- 2006



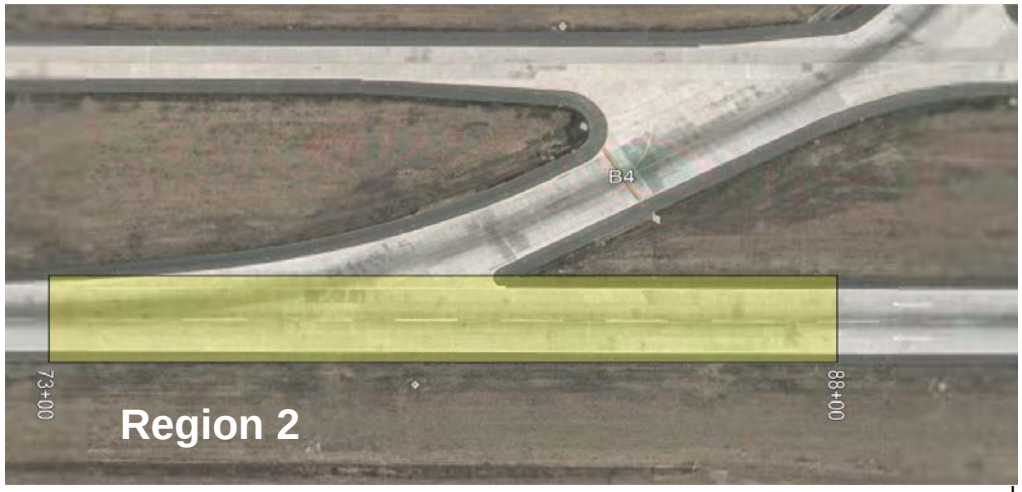
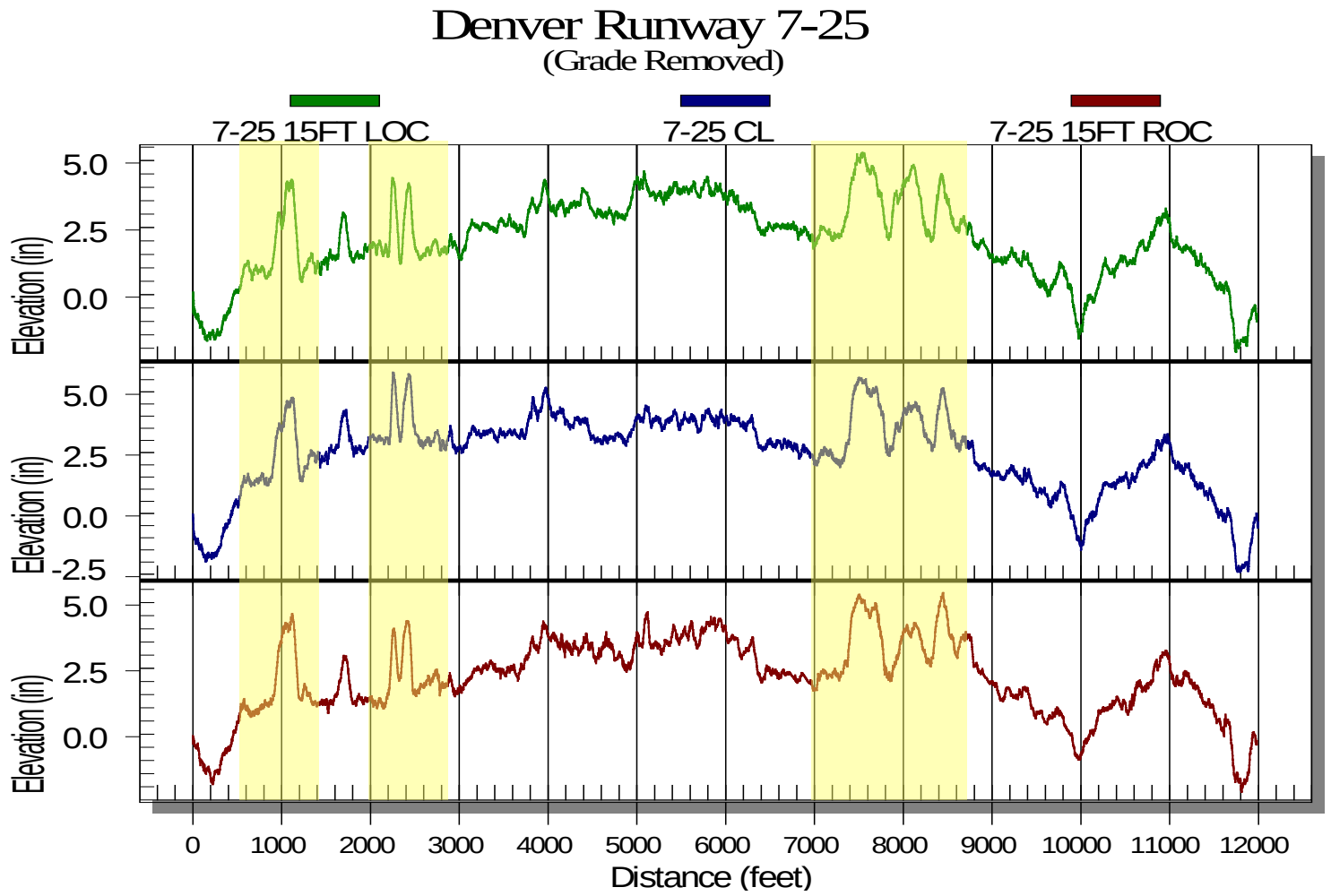
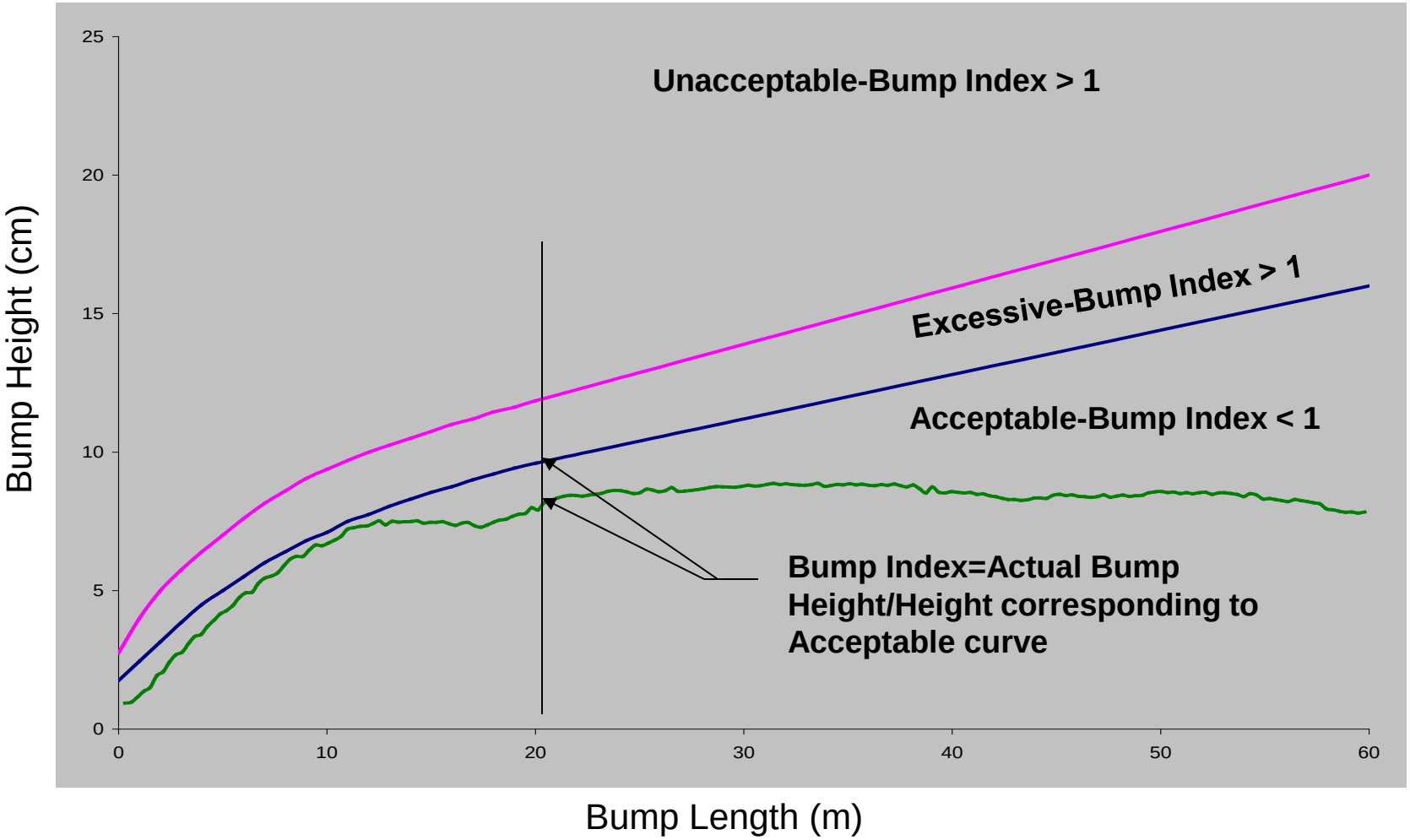


Image: Courtesy Google Maps

APR Profiles-Regions 1 and 2 as noted

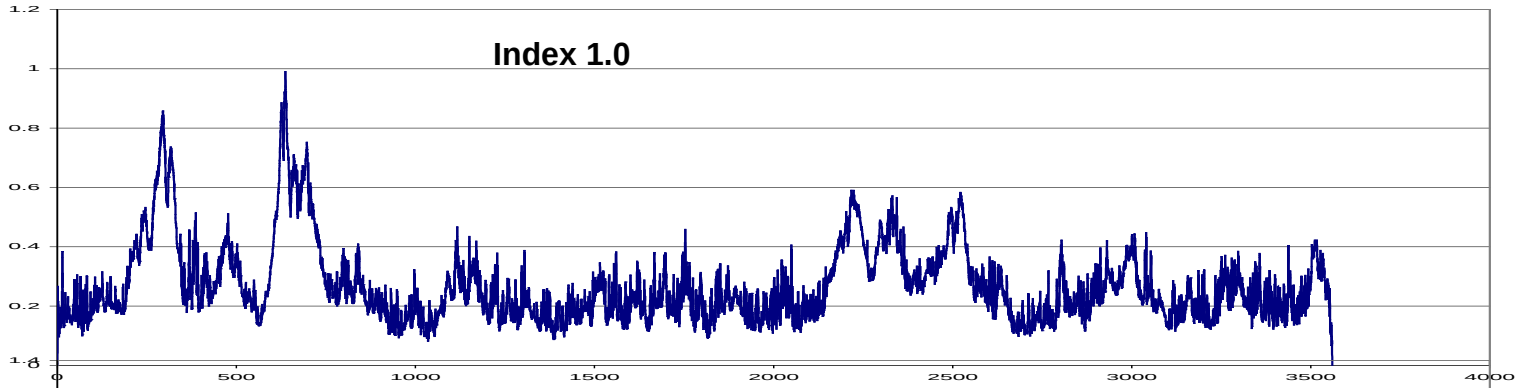


Bump Index Definition- PROFAA method

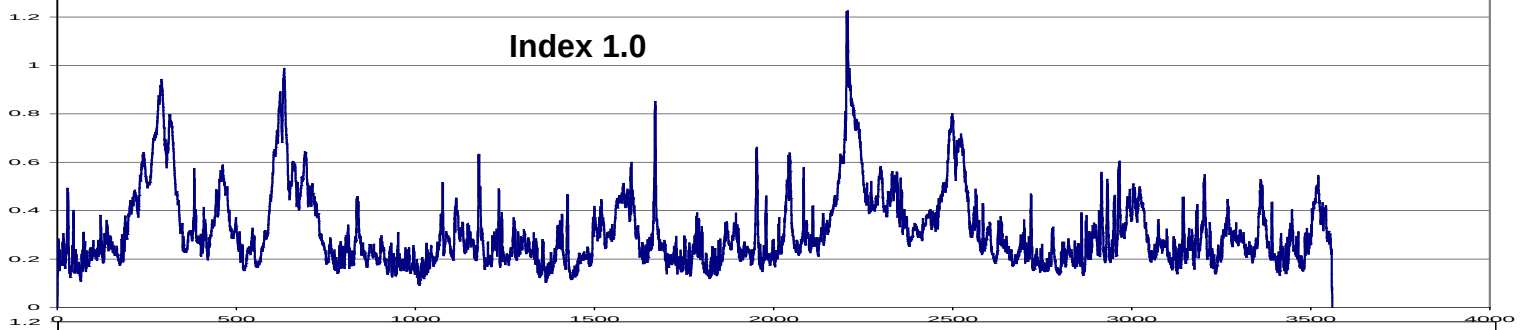


Runway 07/25 Centerline Profile- Bump Index Comparison

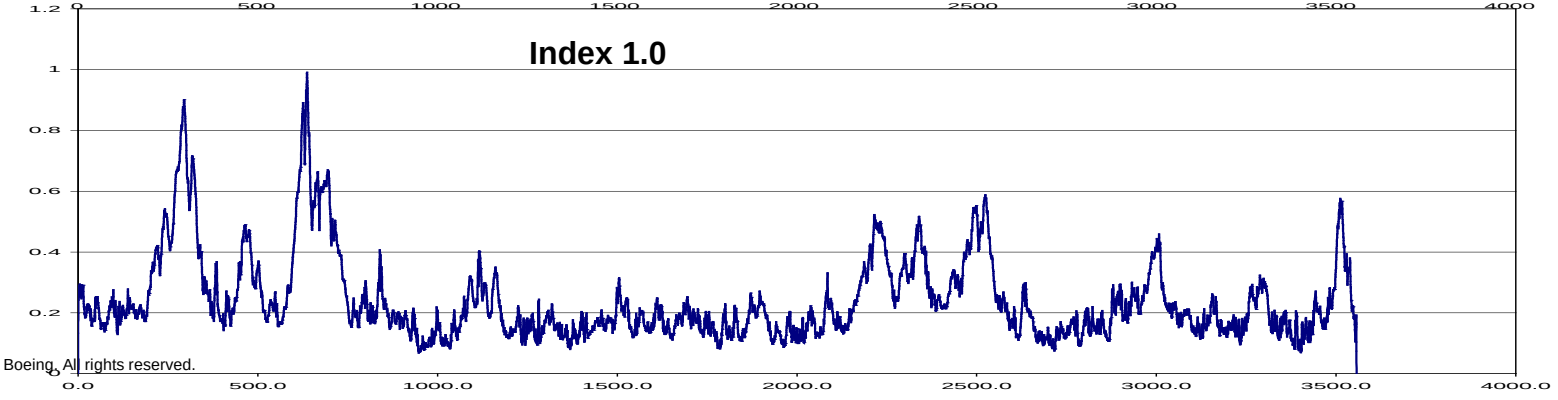
APR



Boeing



FAA



Conclusions

- Profiles from all three devices seem to match well- areas of roughness on runway correlate between all three.
- Boeing bump analysis consistent – bump index values, although differing in magnitude, are maximum at the same locations along the runway
- Locations of overall worst bumps in same areas for all three profiling devices
- All three profilers are useful in determining general areas of roughness needing repair

Case Study 1- Transition Ramp Bump

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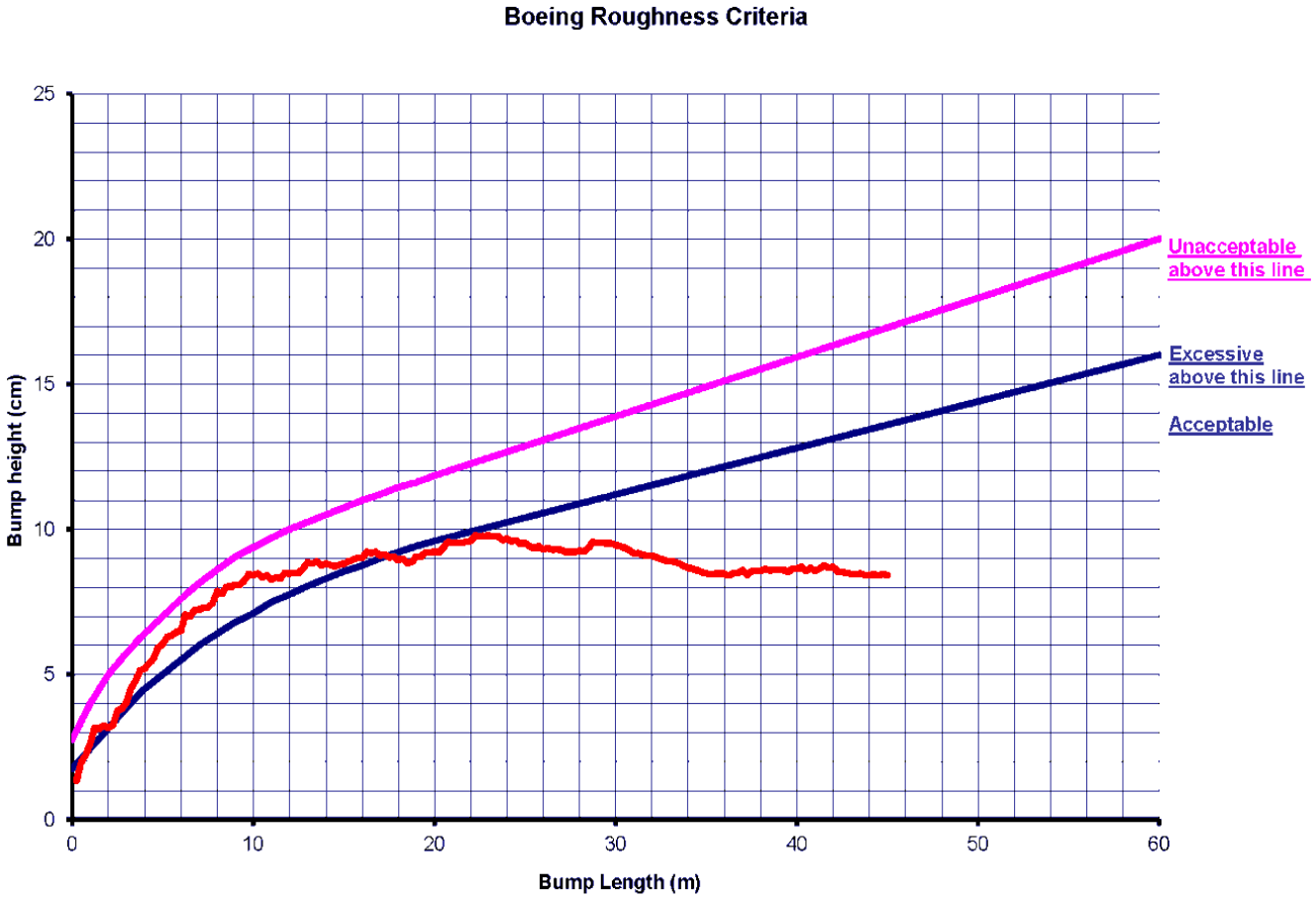


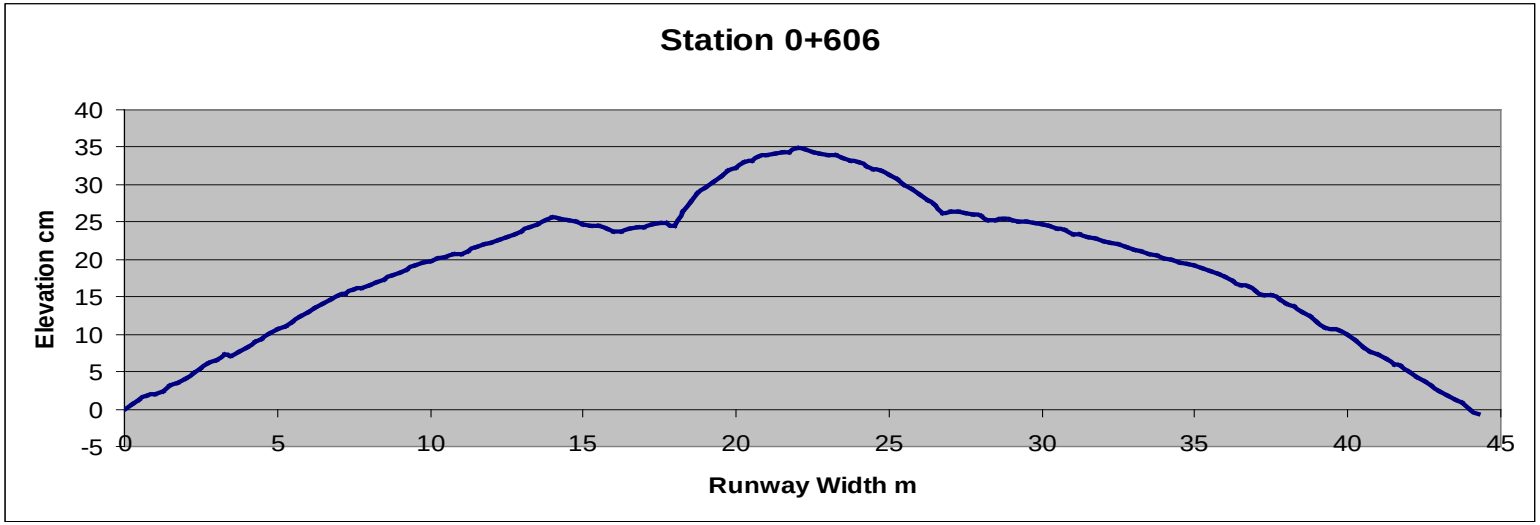
Case Study 2- Lack of Proper Transverse Slope-Runway Contamination

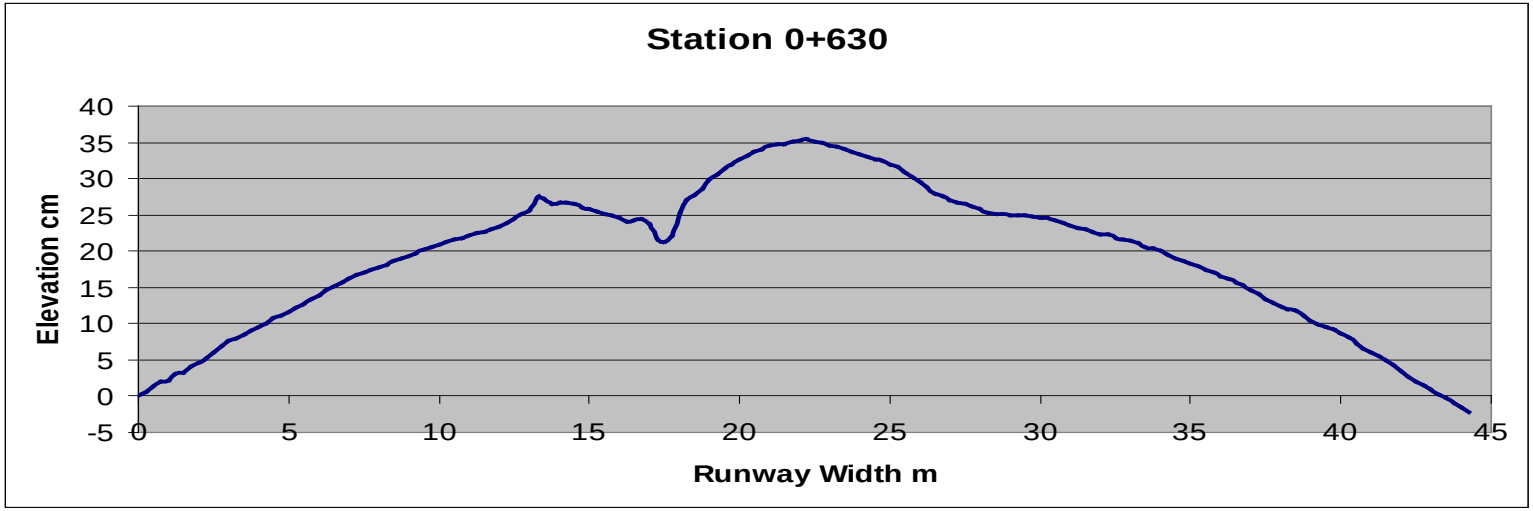
- **Standing water due to improper transverse gradient suspected of causing loss of 777 junction box clamps**
- **Water depth in some areas as high as 2.5 cm and in high speed braking areas. Flight performance manual suggests not taking off when contamination exceeds 1.25 cm, water impingement can cause structural damage.**

Lack of Proper Transverse Slope

Junction box clamps on 777 truck beam susceptible to water impingement due to ponding.

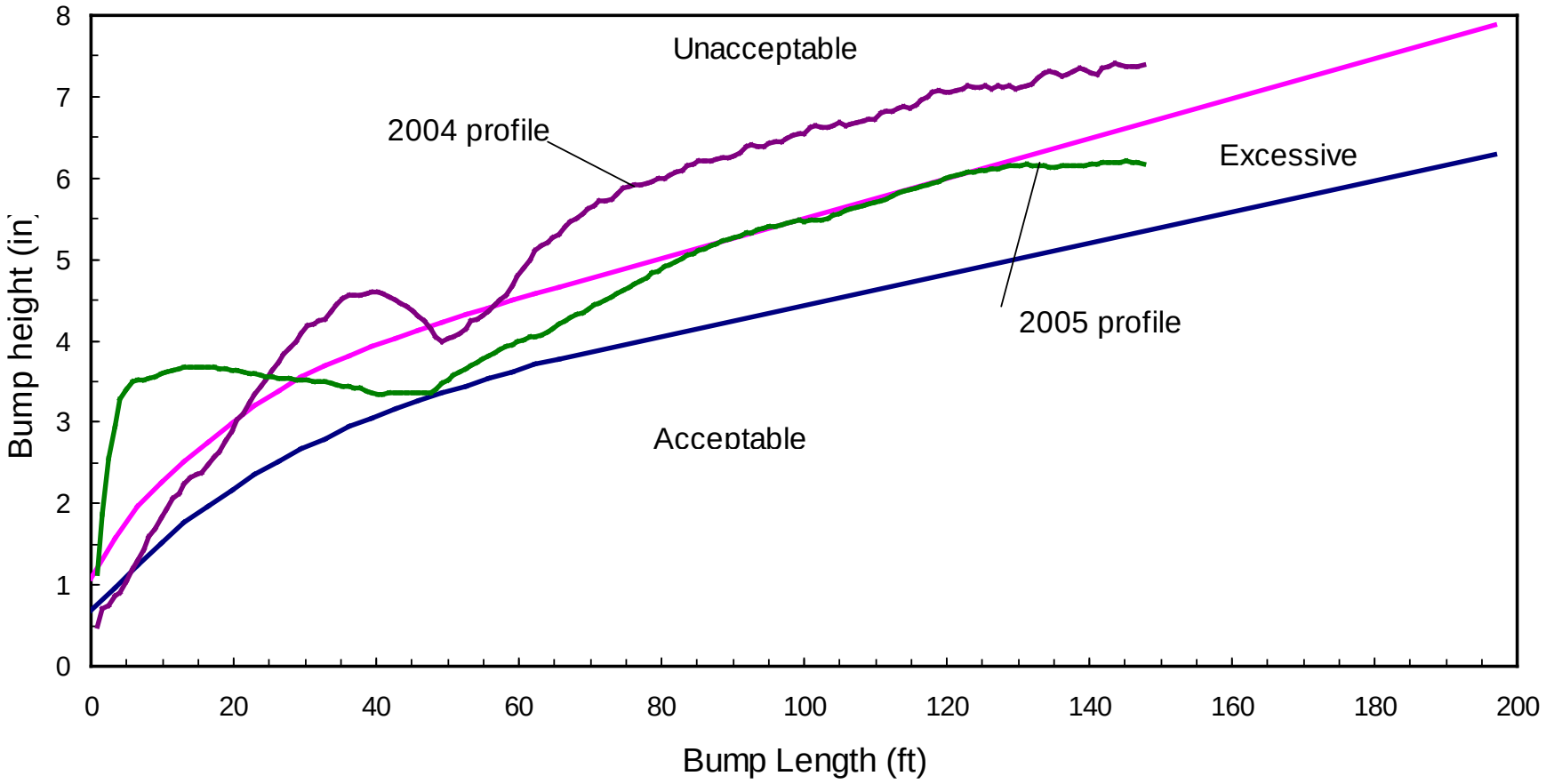
Lack of Proper Transverse Slope



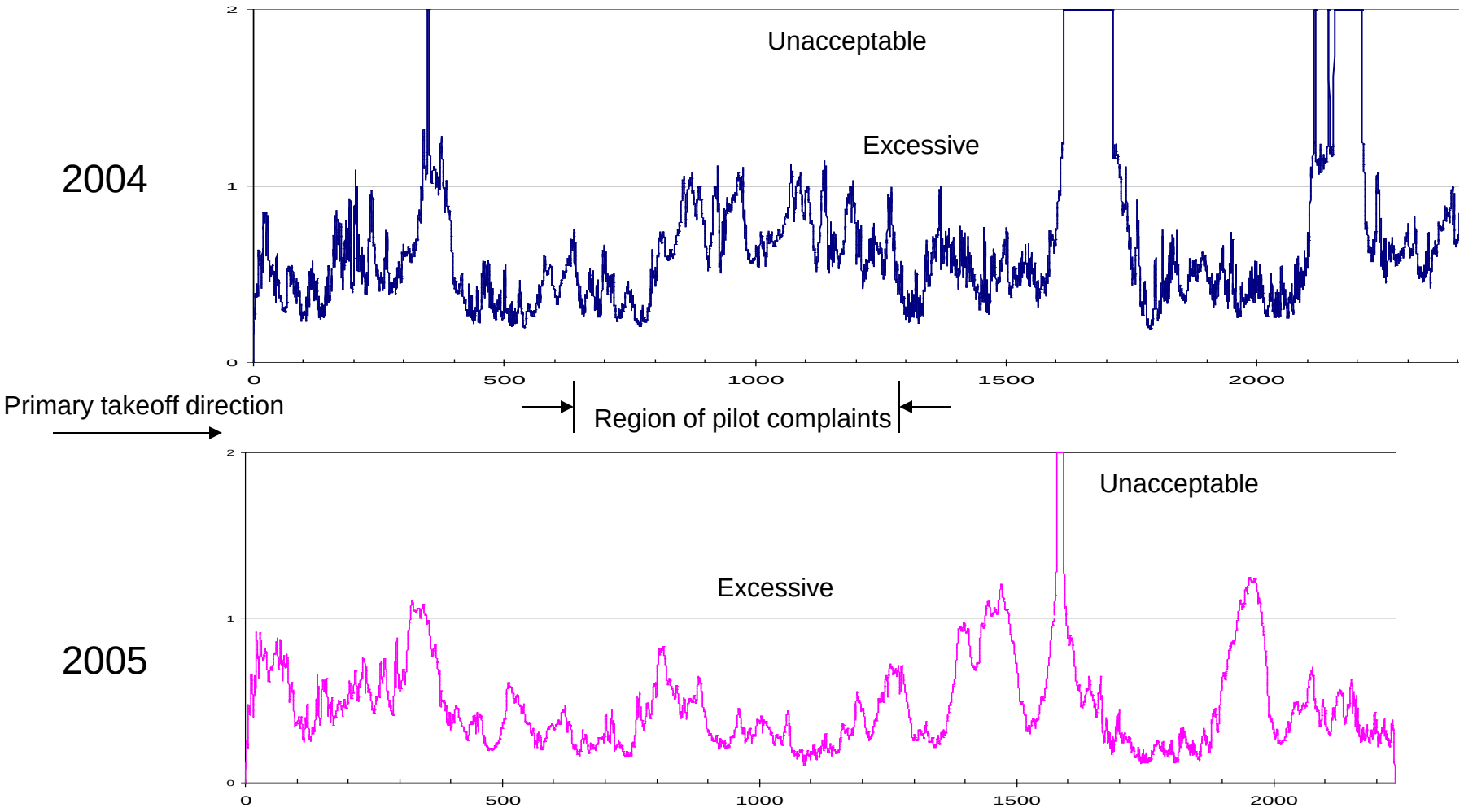


Case Study 3- Unacceptable Roughness Condition

Boeing Runway Roughness Assessment- Unacceptable Condition-Plot of worst bumps



Boeing Runway Roughness Assessment- Unacceptable Condition 2004 vs. 2005 Survey



Working Toward an Industry Standard

Pavement Roughness- Current Situation

- There is no industry standard which clearly defines when a airfield pavement has become “too rough”
- Problems can be aircraft specific
- New construction smoothness criteria is no longer applicable as pavement deteriorates
- Action by the airport is typically initiated by pilot complaints- FAA currently doing aircraft simulator research to assess pilot feedback on runways of varying roughness.

FAA Guidance on Roughness

FAA Advisory Circular 150/5380-9(released 9/30/09)

U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: Guidelines and Procedures for Measuring Airfield Pavement Roughness | **Date:** 9/30/2009 **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 identified by surface profile data of rigid and flexible airport pavements. The guidance in this AC provides technical procedures to quantify surface irregularities and to determine how surface irregularities may affect specific categories of airplanes.

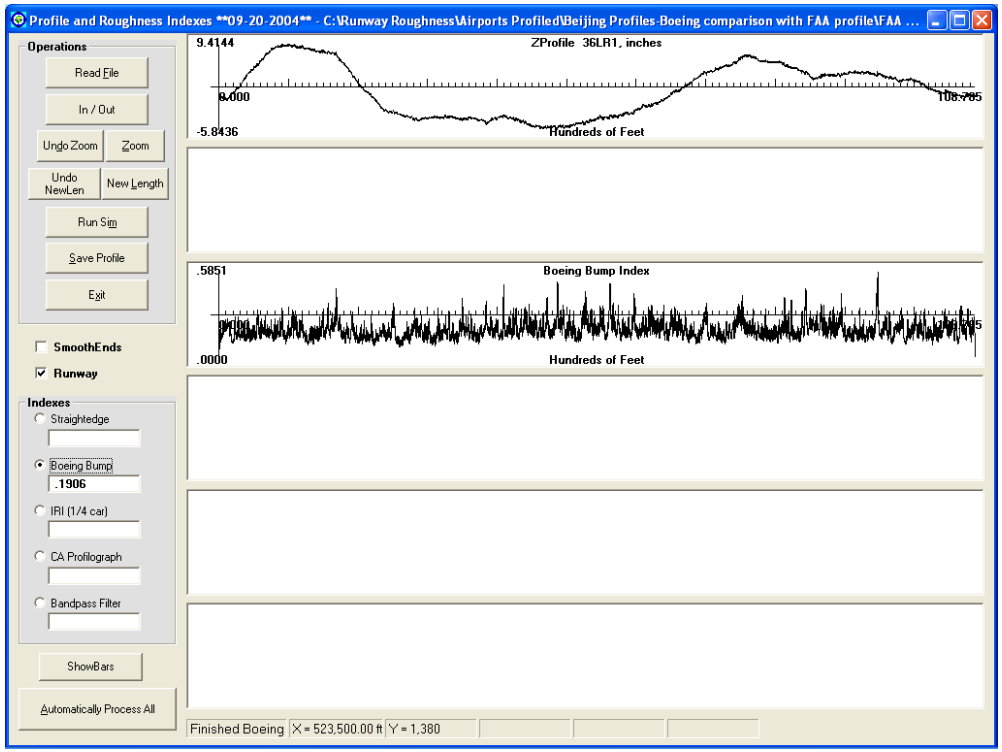
2. **APPLICATION.** The FAA recommends the guidelines and standards in this AC for evaluating the roughness of new and existing paved surfaces. In general, use of this AC is not mandatory. However, use of this AC is mandatory for all projects funded with federal grant monies through the Airport Improvement Program (AIP) and with revenue from the Passenger Facility Charges (PFC) Program. See Grant Assurance No. 34, "Policies, Standards, and Specifications," and PFC Assurance No. 9, "Standards and Specifications."

3. **RELATED READING MATERIAL.** Appendix 1, Bibliography, lists further guidance and technical information.

4. **METRIC UNITS.** To promote consistency with International Civil Aviation Organization (ICAO) guidance, the text and figures include both metric and English dimensions. Dimensions are provided first in metric units. Readers should keep in mind that English units are based on operational significance and

FAA Software PROFAA

Includes Boeing Bump



FAA Guidance on Roughness

NEW CONSTRUCTION

AC 150/5300-13, Airport Design

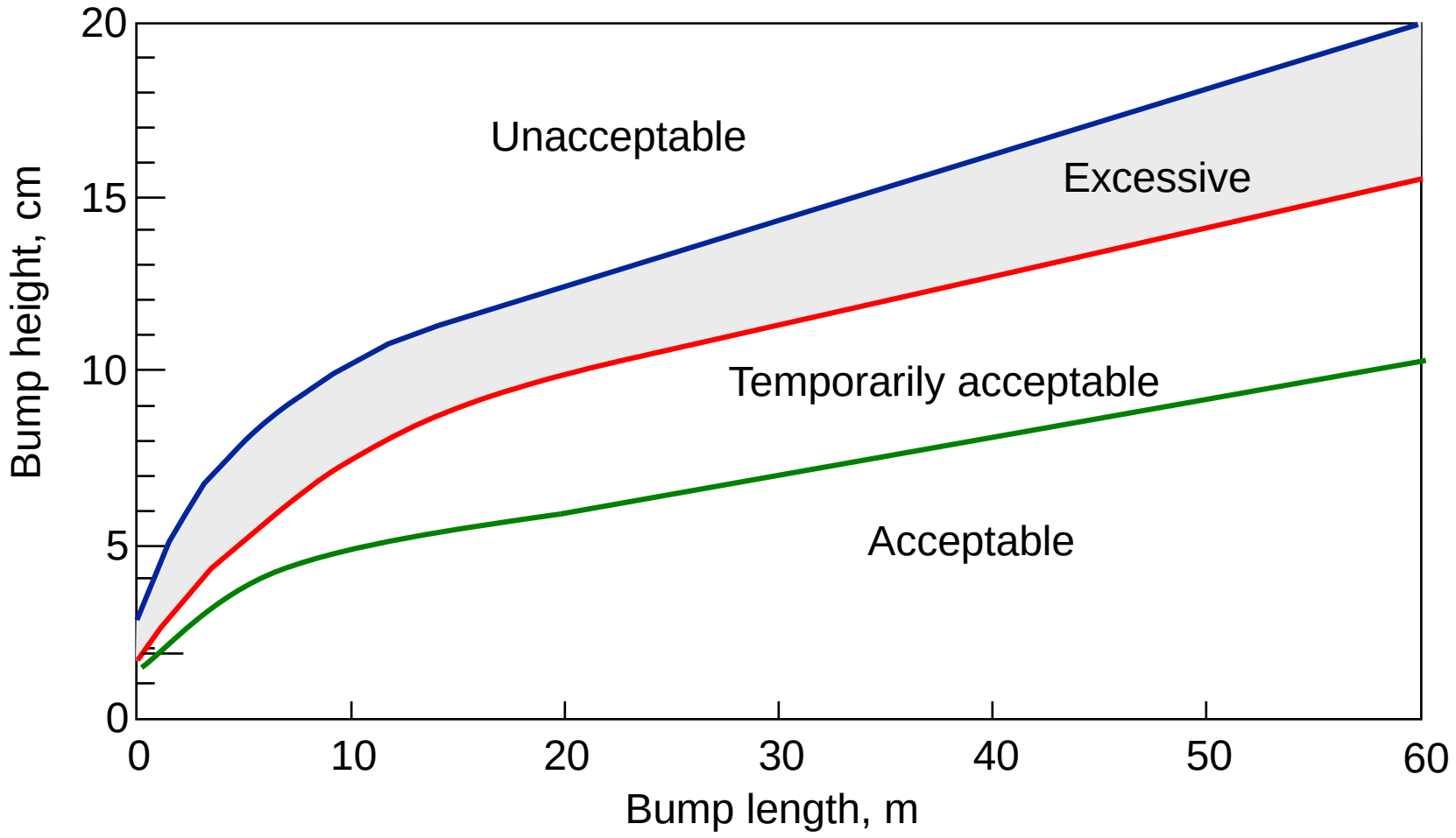
- Surface Gradient
- Maximum grade allowance
- Change in grade provisions

AC 150/5370-10F, Standards for Specifying Construction of Airports

- Construction tolerances must be met
- Acceptance criteria for smoothness- straightedge or profilograph

Experience has shown that the current FAA grade and straightedge criteria provide pavements that are safe for aircraft operations.

ICAO Roughness Curve Approved for Annex 14, Amendment 10, 4th Edition



ICAO Guidance- Annex 14, Attachment A Surface Unevenness

Surface Irregularity	Minimum acceptable length of irregularity (m)								
	3	6	9	12	15	20	30	45	60
Maximum surface irregularity height (cm)	2.9	3.8	4.5	5	5.4	5.9	6.5	8.5	10
Temporary acceptable surface irregularity height (cm)	3.9	5.5	6.8	7.8	8.6	9.6	11	13.6	16
Unacceptable surface irregularity height (cm)	5.8	7.6	9.1	10	10.8	11.9	13.9	17	20

If the maximum limits are exceeded, corrective action should be undertaken as soon as reasonably practicable to improve the ride quality. If the temporarily acceptable limits are exceeded, the portions of the runway that exhibit such roughness should have corrective measures taken immediately if aircraft operations are to be continued. If the unacceptable limits are exceeded and the roughness resides in the area of aircraft operations, then the runway should be closed until repairs are made to restore the condition to the acceptable region.

The maximum permissible step type bump, such as that which could exist between adjacent slabs, is simply the bump height corresponding to zero bump length at the upper end of the acceptable region of the roughness curve. The bump height at this location is 1.75 cm.

Recommendations for ASTM standard

- Recommended to take 3 profiles along entire runway length. One along centerline, and one each either side of centerline between 3-6m offset depending on aircraft gear configuration
- Profile interval spacing should not exceed .5m for best results
- Profile equipment tested all produce similar results and can be used for roughness profiling.
- FAA roughness program PROFAA can be used for Boeing Bump analysis. Profile smoothing similar to Boeing program and areas of roughness correlate well. Details for program usage found in AC 150/5380-9.

Conclusions

- Aircraft are susceptible to three types of roughness, and the Boeing Bump Criteria addresses long wavelength type roughness, and to some extent fatigue loading effects on aircraft. Short wave roughness typically only a concern in Russia and the CIS due to poor construction techniques.

- Typical roughness problems based on Boeing experience in this area are the result of the following: Poor maintenance, failures in base and/or subbase materials, clay soils and issues dealing with moisture, and improper use of transition ramps.

- Guidance is needed for airports on how to address and measure roughness. Recent ICAO acceptance of the Boeing Bump, working towards developing an ASTM standard, and the FAA advisory circular and PROFAA software all provide technical guidance in this area.