

**SEMINAR ON AIRFIELD PAVEMENT MAINTENANCE AND SHORT COURSE ON
THE AIRCRAFT-PAVEMENT INTERACTION**

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HANDOUT

**PRACTICAL MANUAL ON THE
AIRCRAFT-PAVEMENT INTERACTION AND
RUNWAY ROUGHNESS EVALUATION
(Short Course)**

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INTRODUCTION

During the 1st AGA/AOP/SG meeting carried out in Bahamas, from 12 to 15 June 2001, it was observed that the aircraft-pavement interaction and runway roughness are issues that need to be seriously considered in both ICAO Regions, CAR and SAM.

Runway surface quality interests the airport infrastructure designers, airport operators, maintenance engineers, aircraft designers, pilots, crews and passengers.

The detection of the runway critical rough areas that can cause hazard and discomfort mentioned before is very important. In addition, a good method or procedure for correctly identifying these areas contributes to save an expressive amount of money once there is no need of intervention on the entire runway.

The best way to start talking about runway roughness is to know the main aspects that can interfere on the aircraft-pavement interaction as it is presented in the next topic.

2

AIRCRAFT-PAVEMENT INTERACTION

There are two main sources of variables that contribute to the Aircraft-Pavement interaction: the aircraft and the pavement.

Figure 2.1 shows, in a very simple way, the main two parameters of a wavelength, the length and the simple amplitude.

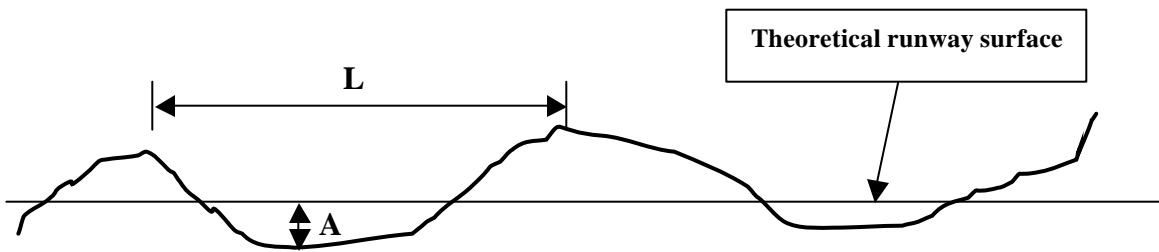


Figure 2.1 – Wavelength main parameters (length and single amplitude)

Where:

L = wavelength

A = Single amplitude

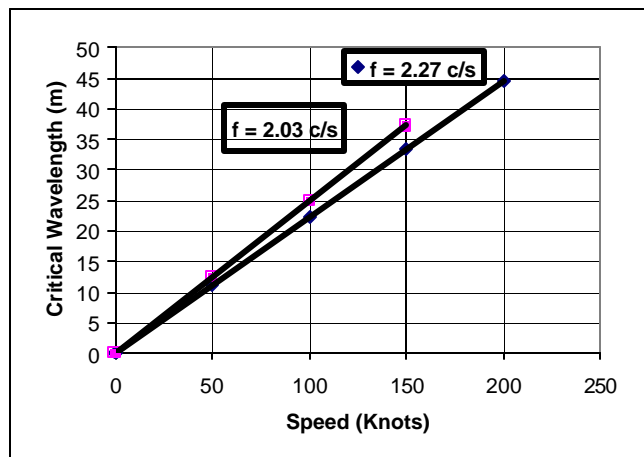


Figure 2.2 – Critical wavelength variation with the aircraft speed (F-5B and F-5E)

It is important to stress that aircraft respond to other pavement characteristics such as superficial macro and micro texture and plastic deformation (rut depth). Besides runway roughness, Figure 2.3 shows how these parameters can interfere on the aircraft-pavement interaction. These aspects are not discussed in this manual, at least, for the moment in time.

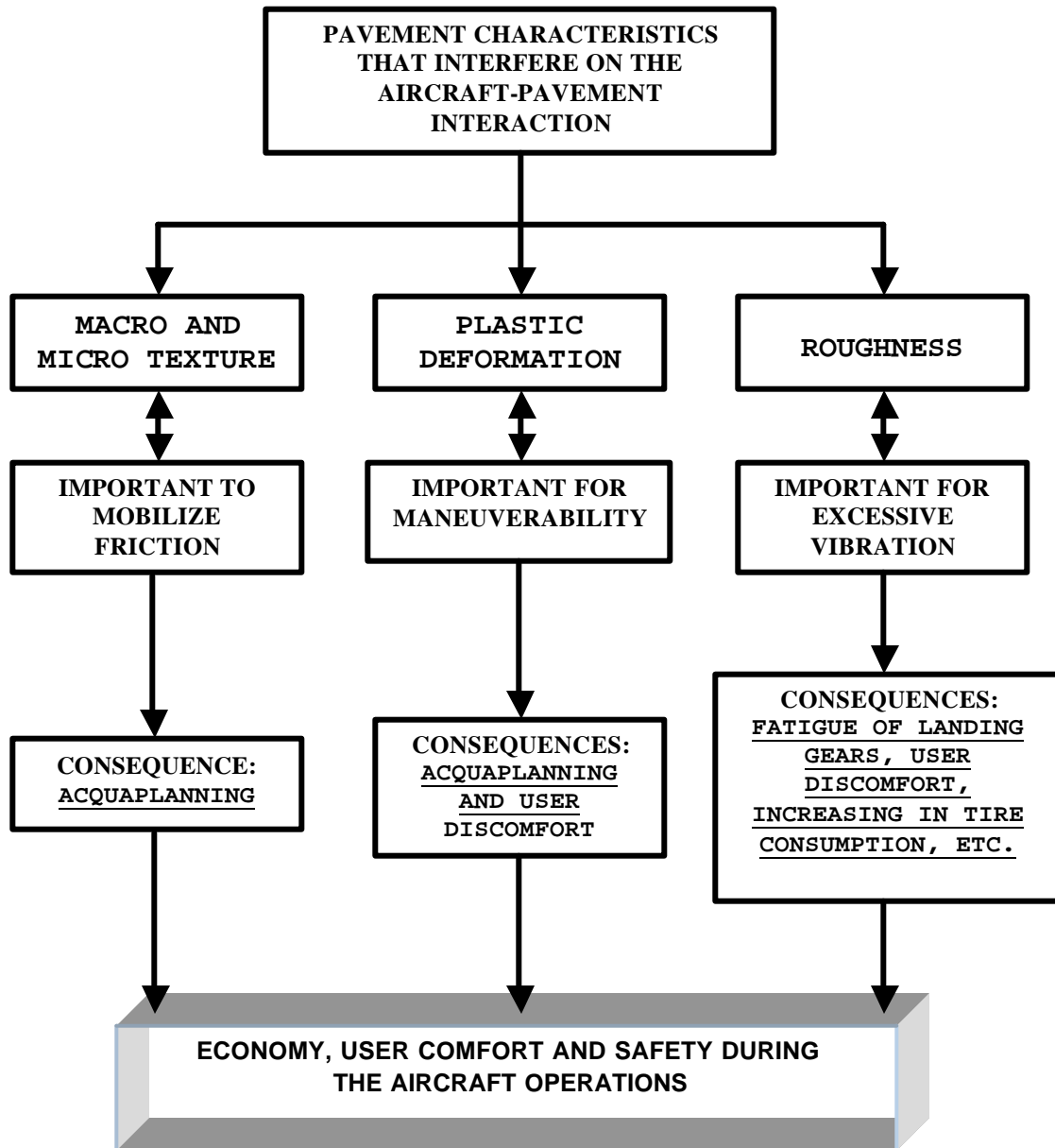


Figure 2.3 – Pavement characteristics that can interfere on the aircraft-pavement interaction

Exercises

- 2.1 *What are the main sources of variables that interfere on the Aircraft-Pavement interaction?*
- 2.2 *What are the wavelength main parameters to be considered in the Aircraft-Pavement interaction?*
- 2.3 *What is the combination that leads to a poor Aircraft-Pavement interaction?*
- 2.4 *How can you explain a resonance problem between the aircraft and the pavement?*
- 2.5 *What types of aircraft has the higher frequency of response, wide body jets or light fighters?*
- 2.6 *It is known that each aircraft responds differently to a runway surface profile. What are the main aircraft parameters that contribute for that?*
- 2.7 *Describe other parameters, not directly related to roughness, that can interfere on the Aircraft-Pavement interaction:*

3

BASIC CONCEPTS ON RUNWAY ROUGHNESS

Even if a runway has a “perfect” surface it always shows some irregularities. These irregularities are not harmful if they do not excessively excite the pilot cockpit and other parts of the aircraft with undesirable vertical acceleration.

As presented in Figure 2.1, the main components of a wavelength are the length (**L**) and the single amplitude (**A**). However, it becomes difficult to identify these parameters and to separate them because, usually, the wavelengths do not obey a standard pattern.

One should be aware that small wavelengths do not excite the main parts of the aircraft. This is a very important issue because equipments able to only pick up small irregularities are not suitable for runway roughness evaluation. The results obtained with these types of equipments are meaningless.

In summary, the runway roughness is due to the presence of simple and complex wavelength systems and isolated depressions.

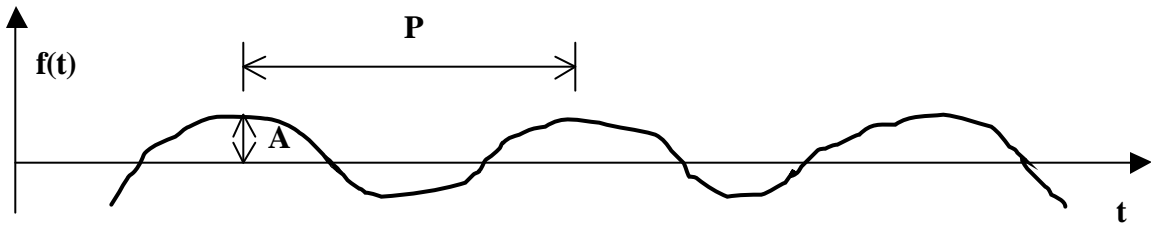


Figure 3.1 – Periodic and simple movement

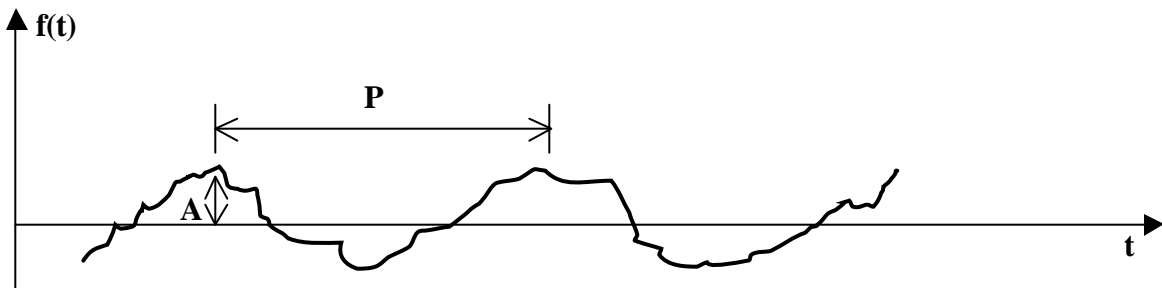


Figure 3.2 – Periodic and complex movement

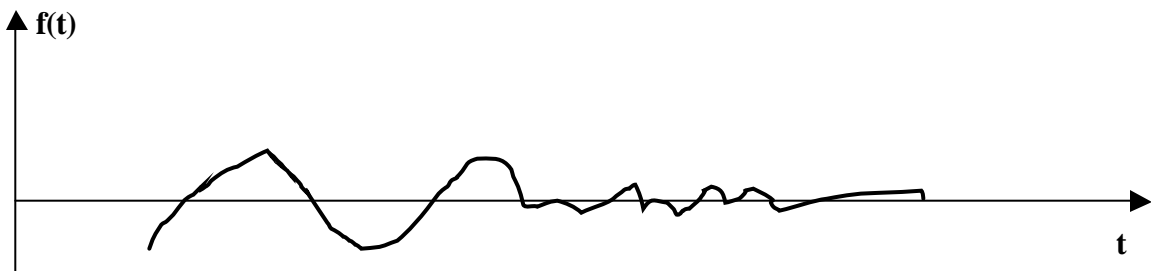


Figure 3.3 – Transient movement

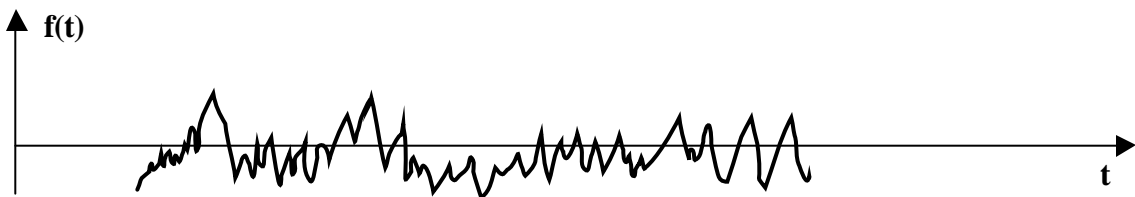


Figure 3.4 – Random movement

Where:

A = amplitude

P = period

t = time

f(t) = time function

Exercises

3.1 How would you describe runway roughness?

3.2 What are the main components of the wavelength?

3.3 Why is it difficult to identify and to separate the main components of the wavelengths at the runway surface?

3.4 What type of wavelength is more important for aircraft at runway surface, long or short?

3.5 An aircraft has a frequency of response equal to 2 c/s. Its speed at the point of rotation is around 120 Knots. What should be the maximum wavelength of interest for you to be considered during a runway roughness evaluation?

4

CAUSES OF RUNWAY ROUGHNESS

Runway roughness can have its origin from several causes such as:

- Airport site
- Construction quality
- Aircraft loads
- Higher tire pressures
- Higher speeds
- Stresses and Strains
- Evolution of small depression
- Dynamic loads
- Transference of kinetic energy to the pavement

Exercises

4.1 How can an airport site selection be a problem for excessive roughness at runway surface?

4.2 List three factors that can cause excessive roughness at runway surface.

4.3 Do you think that the operation of the new large aircraft can generate more runway surface roughness?

4.4 Explain your answer for question 3.

5

AVAILABLE APPROACHES FOR RUNWAY ROUGHNESS EVALUATION

Basically, there are four types of methods that can be used for runway roughness evaluation: aircraft vertical acceleration, simulation of the aircraft response to true runway surface profiles, indirect measurement of the runway surface profiles by using inertial profilometers and direct measurement of the runway surface profiles.

Aircraft Vertical Acceleration

One of the approaches to investigate runway surface irregularities is to analyze the response of the aircraft in terms of vertical acceleration in different parts of the aircraft, such as: cockpit, center of gravity, tail, wings, etc.

Experiences have shown that the most sensitive part of the aircraft is the cockpit. The US Air Force has indicated the limit of 0.4 g (g = gravity) as the maximum vertical acceleration accepted in the cockpit.

For runway construction or reconstruction, the allowed vertical acceleration is 0.2 g in the cockpit.

Simulation of the Aircraft Response

In this approach, a computer program simulates the aircraft response passing over a true runway surface profile. Usually, the profiles are obtained with rod and level.

Use of Inertial Profilometers

There are several profilometers in the market. However, the most famous is the SDP (Surface Dynamics Profilometer).

Other inertial profiles available are: the FHWA (Federal Highway Administration) Profilometer, French APL (Longitudinal Profiler Analyzer) Profilometer, etc.

There are other more simple profilometers available, but not able to estimate long wavelengths in an accurate way.

Direct Measurement of the Runway Surface Profiles

The first approach used to evaluate runway roughness was the direct measurement of the profile in the early 50's. Different techniques, such as *Power Spectral Density*, were used in order to analyze the runway profiles. The discussion of these techniques is not in the scope of this manual. The elevations were taken, at that time, at 60 cm (2 ft)-intervals.

Exercises

- 5.1 *What are the main approaches available for runway roughness evaluation?*
- 5.2 *What method or methods would you suggest for developing a research on runway roughness evaluation?*
- 5.3 *What is the most reliable approach to evaluate runway surface roughness? What is its main disadvantage?*

6

PRACTICAL METHOD FOR RUNWAY ROUGHNESS EVALUATION USING ROD AND LEVEL

The main characteristic of this method is its reliability, a common property of methods that are based on the measurement of true runway surface profiles. The initial works for developing this method were started in 1979. Since then, the author has continuously improved it.

Development of the Method

The Division of Engineering of the Brazilian Air Force, considering several longitudinal profiles obtained from the runways of two air bases, Santa Cruz Air Base, in the state of Rio de Janeiro and Canoas Air Base, in the state of Rio Grande do Sul undertook this study.

The author started the theoretical studies in 1979 and they were the basis for his Master's degree, obtained at the Federal University of Rio de Janeiro, under the guidance of Professor Dr. Jacques de Medina, in 1982.

Behind the development of this method there are deep theories involving Soil Mechanics, Pavements, Aircraft Operations, Vibrations, etc. These aspects are not part of the scope of this manual. However, some principles how the method works is presented as follows.

How the method works

The method works according to the following steps.

6.1. Define the longitudinal alignment(s)

Ideally, longitudinal profiles should be obtained at runway centerline, left and right side of runway centerline. The distances of the profiles from the runway centerline depend upon the critical aircraft indicated by the pilot complaints.

6.2. Field work

The fieldwork consists of the survey of the runway elevations at 1 m interval with rod and level.

The best way to speed this process up is to put marks at every 1 m in one rope 20 m long (or a scale 20 m long). By doing this, the worker rapidly displaces the rod over the rope without wasting time trying to identify the 1 m interval on the runway.

6.3. Data analysis

6.3.1 Template approach

The first step in this approach is to draw the runway surface profiles in a 1:100 horizontal scale (cm) and 1:1 vertical scale (mm). This can be done by a drawer or by using a computer. It is worthwhile to recall that the profiles are interrupted at the end of each sheet and they immediately continue one position below. Every time that one goes one position below, it is recommended that the last three points (elevations) be repeated.

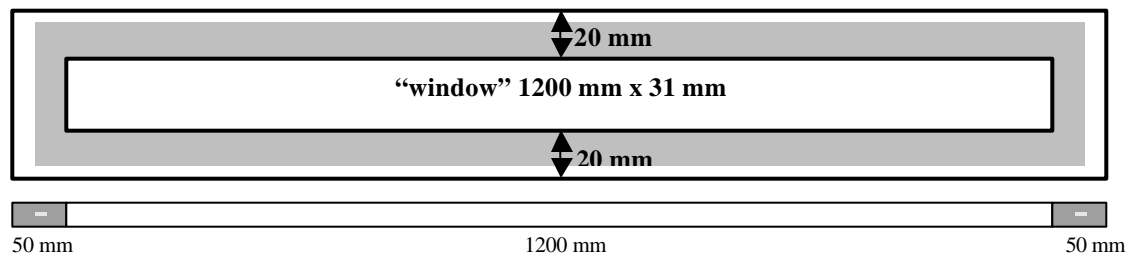


Figure 6.1 – Sketch of the template

6.3.2 Root Mean Square (rms) Approach

This is another way to analyze the profiles also considering each 120 m of runway. In other words, the analysis is done for a set of 120 points, calculating the standard deviation for them, which is equivalent to the root mean square (rms).

Acceptable segment (or runway) P $rms < 8.13$ mm

Segment with marginal value P 8.13 mm $< rms \leq 9.15$ mm

Rough segment (or runway) P $rms > 9.15$ mm

In general, both approaches give similar results. The Boeing approach, as discussed in the next item, can complement these procedures for the case of isolated bumps.

6.3.3 Boeing approach

The objective of this approach is to check if isolated bumps (basins) can cause damage to the landing gear of the aircraft. As indicated in Figure 6.4, there are two curves for this type of evaluation.

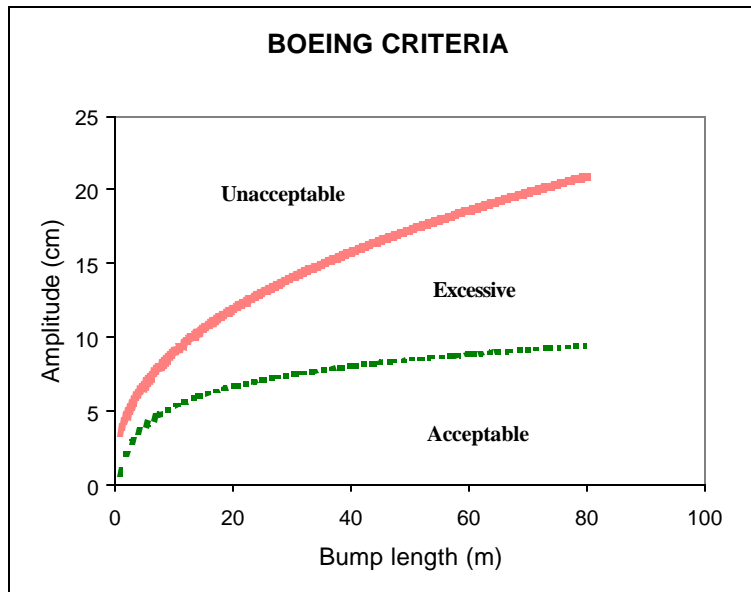


Figure 6.4 – Boeing criteria

6.3.5 Resonance approach

As said in Chapter 2, if an unfortunate combination of the aircraft speed, the frequency of response of the aircraft and the forms of the unevenness at the runway surface occurs the aircraft enters in resonance with the pavement surface.

Example 6.1

Let's assume that pilots of B747-400 start complaining about aircraft vibration and some discomfort in the cockpit during the takeoffs at speeds of around 40 mph. How to check if there is a resonance problem?

- a) Obtain the runway surface profiles;

- b) Observe if there is a periodic wavelength system like in Figures 3.1 and 3.2;
- c) Estimate the length of each wavelength;
- d) Locate the aircraft speed of 40 mph in Table 6.1;
- e) For the column of B747-400, read critical wavelength of 70 m;
- f) If the length of the wavelengths measured in “c” match about this value (70 m), you are facing a resonance problem.

Table 6.1 – Basic information for checking resonance problems

Critical wavelength (m)						
Speed	Type of aircraft					
(mph)	B747-400	MD-11	DC-10-30	A-330	B-727-200	B-737-400
20	35	30	28	27	17	15
40	70	60	57	54	34	29
80	140	120	113	108	69	59
90	158	135	127	122	77	66
100	175	150	141	135	86	73
110	193	165	156	149	94	81
180	315	270	255	243	154	132
190	333	285	269	257	163	139
200	350	300	283	270	171	147

Note: These calculations were done considering the aircraft maximum takeoff weight

Example 6.2

Now let’s assume that B737-400 also operate in that runway. Considering that the length of the wavelengths measured in letter “c” of the example 6.1 lie between 70 and 80 m, what would be the speed for which this type of aircraft would enter in resonance with the runway surface?

- a) Go to column equivalent to the B737-400 in Table 6.1;
- b) Locate the length of the wavelength (70 to 80 m);
- c) Go horizontally to the left and read the speed in the first column of Table 6.1;
- d) The speed is, approximately, between 100 and 110 Knots.

Exercises

- 6.1 How do you define the longitudinal alignments of one runway to be surveyed?
- 6.2 Assume that you evaluated one runway and you have found a very rough area with some isolated bumps. What method would you use to check them?
- 6.3 How would you use the selected method?
- 6.4 Now, imagine that you have found three isolated bumps with the combinations presented in Table 6.2. What would be your evaluation? Design some recommendations, if any, to face this situation.

Table 6.2 – Bump characteristics

<i>Bump identification</i>	<i>Bump characteristics</i>	
	<i>Wavelength (m)</i>	<i>Amplitude (cm)</i>
<i>01</i>	<i>30</i>	<i>13</i>
<i>02</i>	<i>40</i>	<i>8</i>
<i>03</i>	<i>50</i>	<i>2</i>

- 6.5 When does a resonance phenomenon between an aircraft and a runway surface occur?

7

ESTIMATION OF THE LENGTH OF TRANSITIONAL RAMPS FOR RUNWAY REHABILITATION WORKS

ICAO criterion

This criterion states that the longitudinal slopes of transitional ramps, measured with reference to the existent surface or the previous surface course, will be:

- a) 0.5 % to 1.0 % for overlays up to 5 cm thick inclusive; and,
- b) Less than 0.5 % for the overlays thicker than 5 cm.

Usually, the lengths of the ramps calculated by this procedure are long because it does not take into consideration the existent runway longitudinal slopes and their variation.

FAA criterion

This criterion is based on the Equation 7.1.

Equation 7.1

$$L = 15 \times T$$

Where:

L = length of the ramp in ft

T = overlay thickness in inch

Boeing criterion

For applying this approach, one needs to take the elevations of longitudinal alignments of part of the overlay, the ramp itself and the old pavement. The length and the amplitude of the bump are combined and verified through the curves presented in Figure 6.4.

Rms criterion

It is necessary to survey at least a runway segment of 120 m long. The elevations are drawn considering a 1:100 horizontal scale (cm) and 1:1 vertical scale (mm). The profile checked by passing it inside a “window” of a template measuring 1200 mm by 17.6 mm. If the profile “violates” this template, it means that the length of the provisional ramp needs to be increased.

Criterion based on the overlay thickness and natural slope of the runways

Both Boeing and rms criteria were used for developing the equations that generated the curves presented in Figure 7.1. The information gathered from the pilots, operating different aircraft during takeoffs and landings, was the main tool for calibrating the equations. After applying the criterion, no pilot’s complaints were registered except when the workers constructed shorter transitional ramps than indicated by the method.

A summary of the pilot opinions is indicated in Table 7.1.

Table 7.1 – Results based on pilot’s opinion

1998	Distance from 15 end (m)	Ramp length (m)	Existent longitudinal slope (%)	Pilot’s opinion
10 Oct	930	4	0,30	COMPLAINTS (1)
12 Oct	1027,5	4	0,30	“ (1)
13 Oct	1087,5	6	0,62	“ (2)
14 Oct	1187,5	6	0,45	“ (2)
15 Oct	1287,5	7,5	0,85	NO COMPLAINT
16 Oct	1387,5	7	0,20	NO COMPLAINT
22 Oct	1587,5	7	0,25	NO COMPLAINT
23 Oct	1758	7	0,40	NO COMPLAINT
24 Oct	1858	6	0,67	NO COMPLAINT
28 Oct	1970	5	0,69	NO COMPLAINT
29 Oct	2080	4	0,84	NO COMPLAINT
30 Oct	2300	5	0,5	NO COMPLAINT
02 Nov	2385	4	0,63	NO COMPLAINT
03 Nov	2497	4	0,81	NO COMPLAINT
04 Nov	2607	4	0,69	ONE COMPLAINT (1)
05 Nov	2716	5	0,86	NO COMPLAINT
06 Nov	2836	5	0,80	NO COMPLAINT
09 Nov	2956	4	0,85	NO COMPLAINT

(1), (2), respectively, 4.5 m and 6.5 m indicated by the procedure

In summary, the criterion can be used according to Figure 7.1.

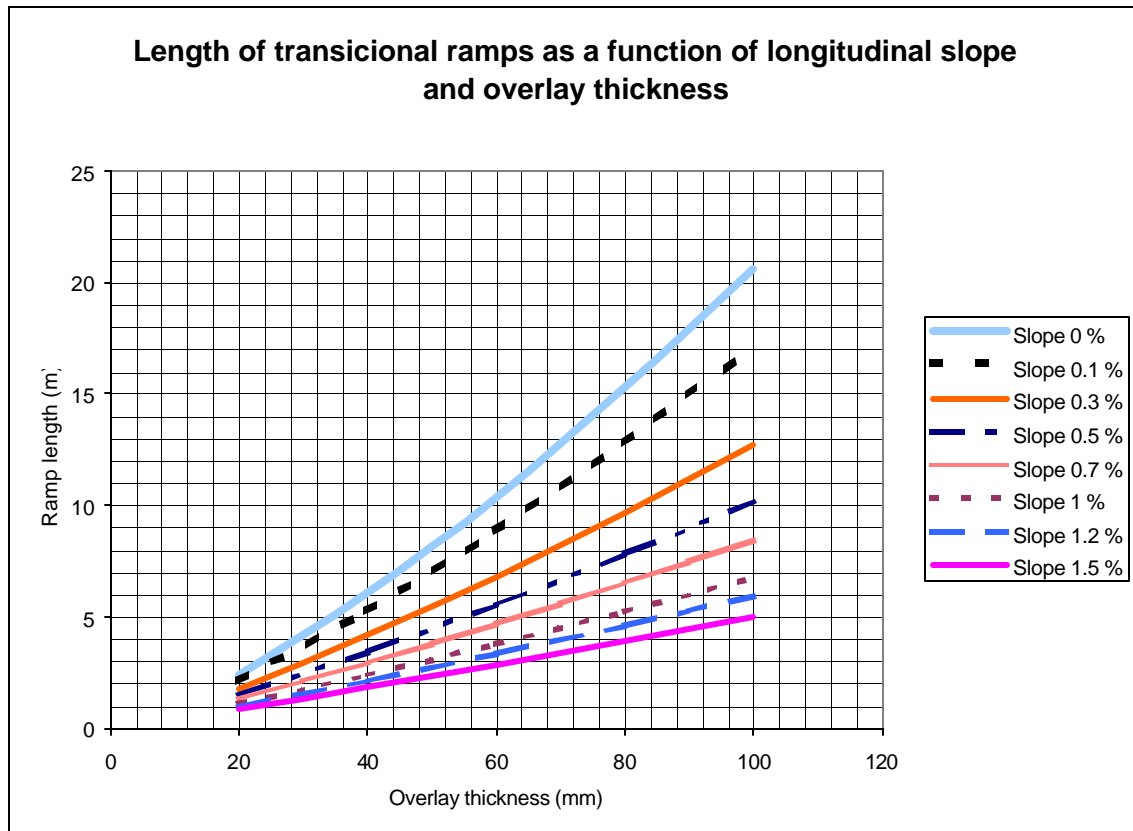


Figure 7.1 – Criterion for estimation of transitional ramp length

Exercises

7.1 A runway is being rehabilitated with an 8 cm overlay.

7.1.1 Estimate the transitional ramp length using the ICAO approach.

7.1.2 Do the same exercise by using the FAA approach.

7.1.3 Knowing that the longitudinal runway slope in that particular area is 0.5 %, do the same exercise by using the method based on the runway slope and overlay thickness.

8

METHODS TO CORRECT RUNWAY ROUGH SURFACES

There are many ways to correct excessive runway roughness. The most conventional of them are thin and thick overlays, reconstruction of areas where the pavement reached its expected life, etc.

The objective of this Chapter, for the time being, is to discuss three cases of different and very peculiar rough runways and how they were fixed.

8.1 Solution for Fighter Aircraft Resonance Problems with Rough Runway

8.1.1 Problem Description

The pilots complained about up and down movements of the aircraft cockpit during takeoffs from 22 end in the last 400 m of the rigid pavement (slabs of Portland cement concrete). The types of runway pavements are indicated in Figure 8.1.

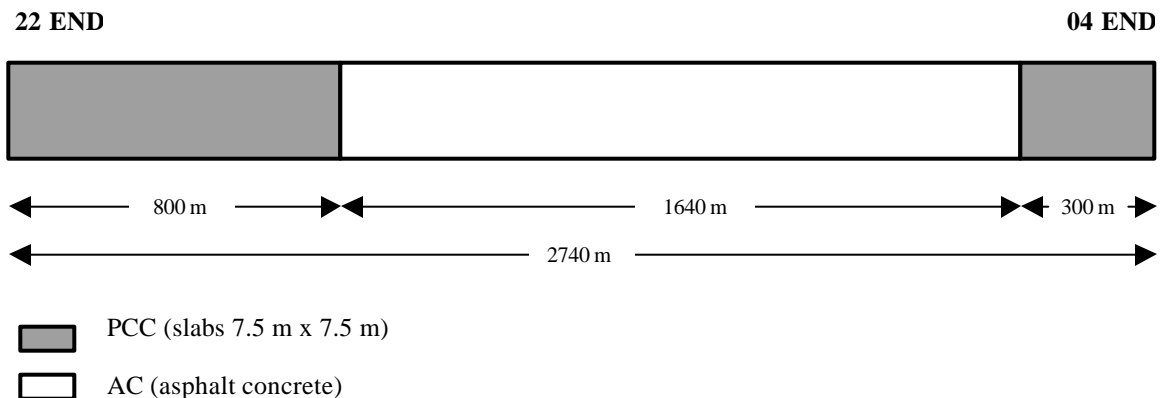


Figure 8.1 – Types of runway pavements

As a consequence, 25 % more speed and 40 % more runway distance were necessary for the takeoff.

It is important to emphasize that the applied methodology permitted the accurate identification of the critical areas. This is basic not only for the diagnosis of the problem but, mainly, for the prescription of the correct solution, as it is discussed in the next item.

8.1.2 Problem solution

The first step was to delimit the area to be corrected, which was defined to be between 460 m and 740 m from the beginning of 22 End.

Table 8.1 – Roughness in terms of rms^(*) measured before and after overlay

Profile position	Distance 22 End (m)	Roughness in terms of rms (mm)		
		Before Overlay	After Overlay	Decrease in %
13m left side RWY CL	440 – 560	10.52	6.65	36.8
	560 – 680	13.22	4.13	68.8
	680 – 800	8.82	5.93	32.8
4.2 m left side RWY CL	440 – 560	12.22	8.20	32.90
	560 – 680	19.69	4.51	77.10
	680 – 800	17.56	7.37	58.10
RWY CL (CenterLine)	440 – 560	11.75	7.55	35.70
	560 – 680	19.85	2.26	88.60
	680 – 800	16.82	4.54	73.00
4.2 m right side RWY CL	440 – 560	13.91	7.48	46.20
	560 – 680	16.80	5.04	70.00
	680 – 800	18.76	5.55	70.40
13 m right side RWY CL	440 – 560	8.11	7.56	6.80
	560 – 680	15.41	4.73	69.30
	680 – 800	22.23	6.50	70.80

() According to the methodology discussed in Chapter 6*

8.2 **Solution for Aircraft-Pavement Interaction Problem on a Pre-Stressed Concrete Runway**

8.2.1 Problem description

Complaints of wide body jet (B-747, DC-10 and MD-11) pilots about the portion of the pre-stressed concrete runway 10/28, of the International Airport of Rio de Janeiro, located between 2000 m and 2300 m from the 10 End, indicated a complicated aircraft-pavement interaction problem.

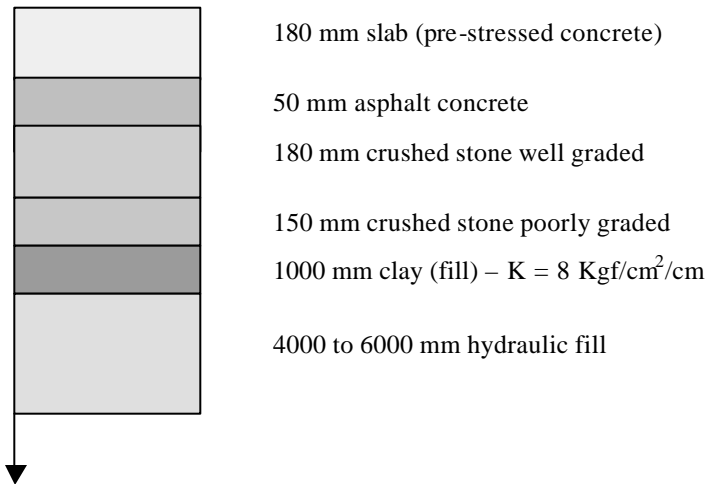


Figure 8.2 – Pavement structure

The Template Criterion and the Runway Roughness Boeing Criteria were able to correctly indicate the rough areas.

8.2.2 Problem solution

Three solutions were delineated in order to repair the slabs of that portion of the runway. They are:

- 8.2.2.1 To mill only 2 cm at the “hill” of the bumps, approximately 10 m long, of the two slabs located side by side of the runway centerline;
- 8.2.2.2 To scarify the entire surface of the two slabs, located side by side of the runway centerline and to fill the “valleys” of the bumps with structural micro concrete until the elevation of the bump “hills”; and,
- 8.2.2.3 To mill 2 cm at the “hill” of the bumps, approximately 10 m long, of the two slabs located side by side of the runway centerline and to fill the “valleys” of the bumps with structural micro concrete until the elevation of the “cut” of the “hills”.

The second option was selected and the repair of the slabs was done in October of 1993, according to the following steps:

It is beyond the scope of this manual, at least for the time being, to more fully discuss all the properties of the components used in the micro concrete. However, Table 8.2 shows some of the properties of the components and the micro concrete, as well.

Table 8.2 – Some admixtures and micro concrete properties

Property	Micro Concrete (*)	Epoxy (SIKADUR 32 BV)	Retarding (SIKAMENT 320)	Micro silica (SIKACRET 950)
Ratio by weight of cement	-	-	1.0 %	15 %
Specific gravity	-	1.65	1.2 – 1.21	-
Color	-	Gray	Brown	Gray
pH	-	-	9 - 11	7 – 9
Initial curing	-	5 h	-	-
Final curing	7 days	7 days	-	-
Compressive strength (28 days)	40 MPa	-	-	-
Flexural strength (28 days)	5.5 MPa	-	-	-
Slump (cm)	3 ±	-	-	-
Water/cement ratio	0.4	-	-	-

(*) *Cement: high early strength*

Ratio: 1:2.38:3.62 (cement/fine aggregate (sand)/coarse aggregate)

Coarse aggregate (granite): 100 % passing # 3/8 sieve; Abrasion (Los Angeles Test): 45 %

The only distress observed, was the development of a few shrinkage cracks just a few days after the curing process. These cracks have not had their openings increased since then.

Up to now, no more complaints were received from pilots of any type of aircraft.

8.3 Solution for Aircraft Jolting Movements on an Asphalt Concrete Runway

8.3.1 Problem description

This problem occurred at the runway 16/34 of the Talara Airport, in Peru. The pilots complained that they felt impacts on B-737 landing gears during takeoffs from 16 End. They also indicated that they could feel aircraft jolting movements, at least in two bumps, after the first 500 m from that End.

Table 8.2 – Length and amplitude of the bumps (Boeing Criteria)

Location (m*)	Alignment	Length (m)	Amplitude (mm)	Allowable amplitude (mm)	Diagnosis
590 to 650	3m left centerline	60	40	92	Acceptable
	centerline	60	60	92	Acceptable
	3m right centerline	50	30	85	Acceptable
825 to 900	3m left centerline	38	30	76	Acceptable
	centerline	75	210**	100	Unacceptable
	3m right centerline	42	50	80	Acceptable
990 to 1030	3m left centerline	10.5	130**	46	Unacceptable
	centerline	9.3	120**	44	Unacceptable
	3m right centerline	10.0	90**	45	Unacceptable
1050 to 1110	3m left centerline	60	60	92	Acceptable
	centerline	52	40	87	Acceptable
	3m right centerline	23	50	63	Acceptable

(*) *Starting from 16 End*

In order to prepare a rational recommendation for the case, a Benkelman bean was used to conduct a non-destructive structural evaluation of the pavement. A multi layer elastic solution was carried out for the interpretation of the deflection basins.

The structural analysis of the pavement indicated that it was very weak in the bump areas and that it needed to be rehabilitated.

8.3.2 Problem solution

The first option, before the runway studies were carried out, was to overlay 1000 m of the runway encompassing the critical portion of the runway reported by the pilots. This solution would modify the runway longitudinal slopes violating the ICAO SARPS.

However, based on the roughness studies and on the non-destructive structural evaluation, three possible solutions were suggested. All of them considered a pavement structural rehabilitation, as described:

8.3.2.1 Suggestion of solution 01: Replacement of the pavement structure as indicated by the structural analysis. In this case, only the 20 m of the central part of the runway would be recuperated. (Cost estimation for this solution: **US\$ 103,000.00**).

8.3.2.2 Suggestion of solution 02: This solution was to apply an asphalt concrete leveling course on the entire width of the runway, between 870 m and 1080 m from 16 End, keeping the original runway slope. A 4” of hot plant-mixed asphalt concrete should be applied over the leveling course. (Cost estimation for this solution: **US\$ 165,000.000**).

8.3.2.3 Suggestion of solution 03: Replacement of the pavement structure of the 20 m of the central part of the runway from 620 m to 1170 m of 16 End. (Cost estimation for this solution: **US\$ 251,000.00**)

The first solution (item 8.3.2.1 was adopted and the pavement structural analysis was carried out for a B-737-400, taking into consideration the following parameters:

Maximum takeoff weight	: 148,632 pounds
Type of landing gear	: Dual wheels
Distance between tires	: 30.5”
Main gear tire pressure	: 185 psi
Load percentage on each main gear leg	: 46 %

Exercises

8.1 Plot the values obtained in Table 8. 2 according to the Boeing Criteria.

8.2 What would be your recommendation for that runway?

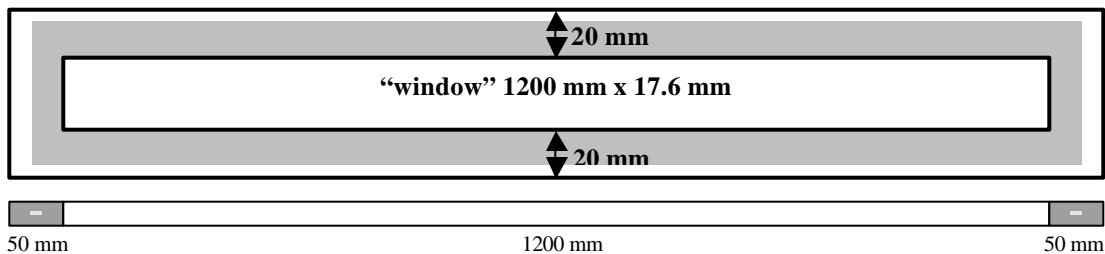
8.3 Please, justify your recommendation.

9

CRITERIA FOR FINAL RUNWAY SURFACE ACCEPTANCE OF NEW CONSTRUCTION OR RECONSTRUCTION

The control of the final quality of the runway surface during construction or reconstruction is a very difficult and important task.

Template criterion



Root Mean Square (rms) criterion

This criterion is based on the calculation of the root mean square (rms) of the elevations of 120 m runway segments. The maximum allowable rms is 6.00 mm.

This approach has a serious limitation because the rms can only be directly calculated for runway with horizontal slope.

Maximum allowable deviation criterion

This procedure was incorporated in the Brazilian standards, in 1985, as Document NSMA 85-2 – “Infrastructure Standard”, of the Directorate of Engineering of the Brazilian Air Force.

1. Take elevations, in mm, at one-meter interval;
2. Calculate the absolute deviations between the elevations taken from the surveying and the elevations recommended by the design. The absolute deviations have to attend the following requirements:
 - a) At least 80 absolute deviations have to be smaller than 6 mm for each 120 m runway segment;
 - b) The maximum allowable absolute deviation is 8 mm; and,
 - c) The absolute deviations between 6 mm and 8 mm must be randomly distributed. It is not allowed more than two successive repetitions of absolute deviations in that interval (6 to 8 mm).

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FINAL NOTE: To obtain the final and complete manual, please, contact Mrs. Nury Torrecilla at nt@lima.icao.int.