HOW SIMULATED AIRCRAFT AIRPORT OPERATIONS CAN IMPROVE AIRPORT PAVEMENT MANAGEMENT SYSTEMS

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ABSTRACT

For road pavement management systems, the International Roughness Index (IRI) has in recent years become the standard for assessing pavement surface roughness. It is based on a quarter-car model traveling the pavement surface at a constant speed. The pavement surface is represented by true geometrical figures; i.e. the longitudinal profile represents the pavement surface. Historically, roughness was assessed with mechanical response systems, which is not a bad concept as the result reflects the undesired effects one wants to mitigate. However, the problem with such systems is that they change over time and that they are more or less individual. Thus, the IRI has been proven to satisfactorily describe pavement performance and pavement deterioration. However, it can be criticized for not being a perfect measure for functional performance. First of all airport traffic does not travel at a constant speed. Secondly, the IRI-filter is not relevant for airplanes at all. Further, current fast non-contact profiling platforms are unable to account for wavelengths in excess of 100 m or so, but a new method of measuring the longitudinal pitch of the sensor platform with respect to the ground seems to be promising and a test was initiated in 1997. In the fall of 2002 an improved system was finally tested. If dozens of profiles can be assessed in a matter of minutes along a runway, larger airports will be able to monitor roughness as a functional and safety criterion much as friction is today. The present paper introduces some of the results of the new profiling methods and discusses how data can be implemented in an Airfield PMS. Some experience of using laser profiler data for overlay design purposes is also presented.

KEY WORDS

AIRPORT PAVEMENT MANAGEMENT SYSTEMS/ PAVEMENT PROFILER

COMMENT LA SIMULATION DES MOUVEMENTS D'AVIONS PEUT AMELIORER LES SYSTEMES DE GESTION DES CHAUSSES AEROPORTUAIRES

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RESUME

L'Indice de Rugosité International (IRI) est récemment devenu l'indice standard d'évaluation de la rugosité des chaussées routières. Il est calculé à partir de la progression à vitesse constante du modèle de suspension “quarter-car” sur une chaussée. La surface de la chaussée est représentée par des valeurs géométriques réelles : autrement dit, le profil longitudinal représente la surface de la chaussée. Autrefois, la rugosité était évaluée en fonction des systèmes de réponse mécanique, ce qui n'était pas une mauvaise idée, les résultats reflétant les effets indésirés que l'on souhaitait mitiger. Cependant, le problème avec de tels systèmes était qu'ils changeaient au fil du temps et qu'ils étaient plus ou moins indépendants les uns des autres. L'IRI s'est démontré capable de décrire de façon satisfaisante les performances de la chaussée et son degré de détérioration. On pourrait toutefois lui reprocher de ne pas être une mesure idéale des performances fonctionnelles. Premièrement, la circulation sur les aéroports, par exemple, ne se fait pas à vitesse constante. Deuxièmement, le filtre IRI n'a aucune signification pour les avions. De plus, les plateformes rapides actuelles de profilage sans contact sont incapables de rendre compte des longueurs d'onde supérieures à 100 m ou plus, mais une nouvelle méthode de mesure du pas longitudinal de la plateforme par rapport au sol semble prometteuse et les premiers tests ont commencé en 1997. Un système amélioré a été finalement mis à l'épreuve en fin 2002. Si des dizaines de profils peuvent être évalués en à peine quelques minutes le long d'une piste, les aéroports les plus importants pourront adopter le suivi du degré de rugosité comme un critère de bon fonctionnement et de sécurité au même titre que l'adhérence aujourd'hui. Le présent document rapporte certains des résultats obtenus grâce à ces nouvelles méthodes de profilage et discute de la façon dont les données pourront être appliquées sur un système de gestion des performances PMS. Sont également présentées un certain nombre d'expériences exploitant les données d'un laserographe pour la conception des couches de surface.

MOTS CLES

CHAUSSEES AERONAUTIQUES / SYSTEMES DE GESTION / LASEROGRAPHE

1. INTRODUCTION

Using profilers to access surface characteristics data is the choice for network pavement managing systems today by most highway agencies. Profilers are also used for production control and as input for CAD programs for overlay design. So far relatively little use for profilers at airports has been accomplished, the reason perhaps being an emphasis on friction and joint deterioration for such pavement surfaces. By tradition, uneven surfaces on airfield pavements have been dealt with primarily as a construction control measure. A 3-meter long straightedge is used for evaluating the longitudinal profiles sampled, as described in an International Civil Aviation Organization (ICAO) guideline. This method will indeed serve as a quality control of the construction and also reveal drainage problems. However, long wavelength roughness will be undetected. Considering the speed of aircraft on runways, wavelengths up to 100 m or more would be of concern. The seasonal variation of unevenness in cold climates is not fully attributable either using too short wavelength for roughness criteria.

In the twenty years that has passed since laser profilers were introduced they have become the working horse of road pavement monitoring in merit of their great capacity. They are very versatile, but are by tradition only used for a limited number of road distress parameters.

On highways, profilers are usually employed for:

- Assessing wheel track rutting
- Assessing roughness, usually the International Roughness Index, but also slope variance and other indices
- Indicate drainage problems, i.e. report cross slope

What profilers can do, but are rarely asked to do:

- Identify *type of roughness*, e.g. in different wavelength bands
- Be used for more sophisticated vehicle modeling than the ¼-car IRI
- Measure texture so that friction can be calculated for various speeds
- Identify *type of rutting*
- Detect cracks and other type of distress
- Measure faulting PCC slabs

In the former group, the cross slope, which is also monitored on highways, and the first three items in the latter group are most viable for airport pavements management systems.

2. SEASONAL VARIATION STUDY

The first use of laser profilers in Sweden was for building a 3D database of a taxiway. It was used for an overlay design using CAD software, not much unlike similar highway projects. However, for airport management systems, the first project was to confirm whether a runway could be rougher in the late winter to spring season due to frost heave. The runway 12-30 at Östersund, (OSD) airport in Sweden was reported to be too rough by pilots. The airport is located inland at latitude 63 degrees North near the Scandinavian Range. The average freezing index is about 1000 degree-days Celsius. Aircraft operations include military as well as civil activities. Local maintenance crews concluded that the uneven pavement surface was likely due to frost heave. Hence, in 1997 it was decided to bring a profilometer to the site at the end of the freezing season. The measurements were repeated at the end of the summer. The material was compared to see if any roughness related parameter could be attributed to frost heave. The appropriateness of such parameters should were also evaluated. Furthermore, the data were collected to be compatible with software, which simulates aircraft body motion.

2.1 Data Assessment

The profilometer was scheduled to arrive to the airport before the event of spring thawing. As it turned out, the runway was first measured in mid-May 1997. The reference encore was carried out in early October the same year. The VTI (Swedish National Road and Transport Research Institute) Laser Road Surface Tester (L-RST) profiler was used for this assignment. Accelerometers record the movement of two optical units measuring the distance to the ground so their movement can be deducted by integrating the signal twice from the accelerometer. This is known as the GM-principle since it was developed at General Motors as in Spangler and Kelley, (Spangler 1964). Thus, two longitudinal profiles are recorded, one for each wheel-path of the vehicle platform. By combining the accelerometer-laser system with an inclinometer and an extra laser range finder (LRF) at the rear of the vehicle, long wavelengths over 50 m could also be assessed.

The L-RST samples and records several other pavement surface distress parameters. In all there are seventeen optical LRF units mounted transversally on a support beam at the front. Some sensors are used for crack detection and macrotexture measurements. This also allows very short wavelengths to be recorded. The 32 kHz sampling rate translates to a reading for each millimeter when traveling at 25 m/s. Other laser sensors are primarily used for assessing rutting, which is of less interest for airports. Parameters gathered included crack detection algorithms, cross slope, macrotexture, and megatexture.

2.2 Outline of Tests

The runway at Östersund is typical for mid-sized airports in Sweden being 2300 m long and 45 m wide. The VTI L-RST covers 4 m of pavement width. To reasonably well cover the entire runway 24 parallel test runs were done along its entire length. Twelve runs were driven towards the northwest and the other half coming back the other way. Consequently, 48 longitudinal profiles were sampled roughly one meter apart from each other. The runway was not closed for airfield operations during the time the tests took place. Thus, each test run had to be made between flight operations. Each run took about two minutes to complete. When the spring measurement was carried out, traffic at the field did not allow the test vehicle to commence until 5:00 p.m. Once started the tests were completed shortly after 8:00 p.m. The fall measurement started at 10:00 a.m. and was completed by 14:30 p.m. the same day. Similar missions have later been proved to be accomplished within this timeframe.

2.3 Roughness Settings

The data collection system assesses the International Roughness Index (IRI) in real time for two wheel paths. Many road authorities commonly use the IRI for pavement management system input and as a functional measure. This measure does relate to vehicle user costs and the performance curve describing the deterioration of the pavement surface over time. Conceptually, it is a filter of the road profile for a one-wheel vehicle traveling at a constant speed of 80 km/h. Hence, even if the performance curve related to deterioration could be used for airport pavements it is less suited for airplanes traveling at accelerating or decelerating speeds. By using the TAKE-OFF software however, the movements are simulated at varying speeds. The movements must however be related to a specific aircraft and typical take-off and landing procedures. Therefore, six different intervals of wavelengths were also calculated as root mean squares. In addition, fine macrotexture, rough macrotexture and megatexture wavelengths were collected, although the three categories were outside the scope of the present study. Reduced accuracy is to be expected for wavelengths of 50 meters or longer.

Table 1: Unevenness root mean square wavelengths, [m].			
Fine Macrotexture	0.005	-	0.01
Rough Macrotexture	0.01	-	0.1
Megatexture 0.5		0.1	-
Short Narrow Range	0.5	-	1
Intermediate Narrow Range 1	1	-	3
Intermediate Narrow Range 2	3	-	10
Long Narrow Range	10	-	30
Wide Range 30		0.5	-
Full Range	0.5	-	100

The various wavelength bands were extracted from the data stream and evaluated so that the two testing occasions could be easily compared. The data were also fed into a computer program developed for road pavement management analysis. This program normally uses rutting and the IRI as inputs. However, it accepts other parameters and thus it was possible to see if the data met some preset criteria. In addition traditional straightedge criteria were also tested. The data were also prepared to be compatible with the computer program TAKE-OFF simulating a given aircraft taking off at the field.

2.4 Straightedge Comparison

A 3-meter long straightedge was used for evaluating the longitudinal profiles sampled, as described in an International Civil Aviation Organization (ICAO) guideline. A computer program developed by VTI uses the sampled profiles and reports deviations larger than certain preset values. The difference between spring and fall tests was remarkably small. Apparently, the frost heave does not influence this particular fixed wavelength produced by the straightedge much. It is questionable if this method is a significant indicator of the frost heave aspect, at least for the present case.

2.5 Wavelength Evaluation

All L-RST right-side unevenness data were extracted and evaluated in the various wavelength bands. The average for each longitudinal profile was then calculated for the two occasions. It was found that the average roughness varies quite a bit across the width of the runway. The near edge profiles are typically more uneven, but the runway is also somewhat rougher along those lines where the main gears of most aircraft travel. What is really interesting though is the difference between the spring and fall measurements for some of the wavelength intervals involved. Figure 1 shows the relative difference for spring values divided by fall values across the runway width.

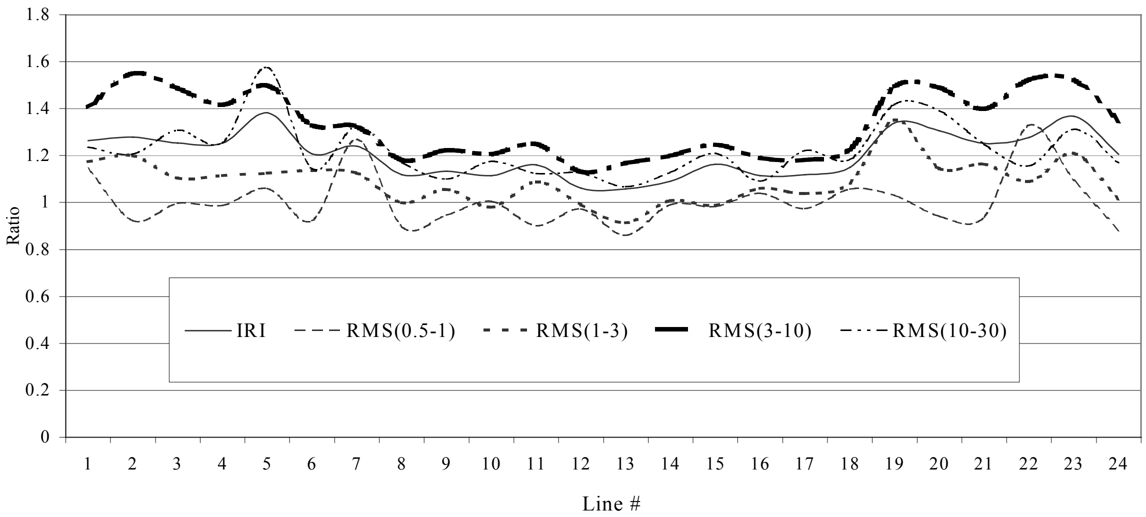


Figure 1: Spring/Fall Ratio across Runway

Clearly, the shortest wavelengths are little affected by the frost heave. In fact the 0.5-1 meter interval often shows better values during the spring. One has to bear in mind though that this result may be related to pavement wear between the two tests. With the exception of the 1-3 meter interval, all other wavelengths show a large difference between the two tests. The 1-3 meter interval differs more than the 0.5-1 meter one though. Also seen in the Figure is that the roughness is more affected by frost heave at the edges of the runway. This does not necessarily imply that the actual frost heave is less at the runway centerline, only that the difference between spring and fall roughness is less accentuated.

The average values for the entire width and length of the runway are given in Table 2 below. The 3-10 meter interval shows the most change, 33% higher values during the spring. A power spectrum analysis confirms the difference between seasons in this wavelength interval. As such it should serve as good indicator of frost heave occurrence. It is likely that some frost heave action occurs about 1.5-5 meters down from the surface, something that will affect this interval in particular.

Table 2: Average values of spring test versus fall test

Parameter	Spring to Fall Ratio, [%]
IRI	120
RMS(0.5-1)	101
RMS(1-3)	109
RMS(3-10)	133
RMS(10-30)	122
RMS(0.5-30)	122
RMS(0.5-100)	119

Figure 2 shows for the RMS(3-10) values as 100-m averages for twelve profiles along the entire runway during spring. Figure 3 shows the same averages for the fall measurements. There are a few sections that are just as rough during the fall as they are during the spring, but in most cases the pavement is indeed a lot rougher in the spring. Notable is also the particularly rough section at 700-800 m along line #1.

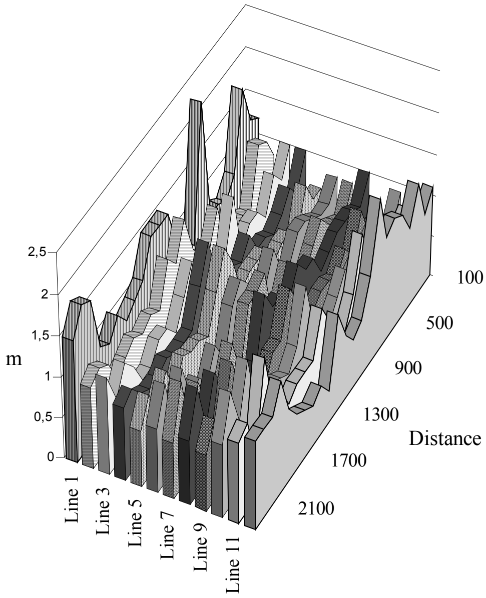


Figure 2: RMS(3-10) Spring

It should be noted that roughness related to near surface defects, e.g. potholes and patches are often related to shorter wavelengths. Settlements on the other hand often affect longer wavelengths. Frost heave occurring near the subgrade naturally influences intermediate wavelength bands. How roughness affects traffic is described by Patterson, [Patterson 1986].

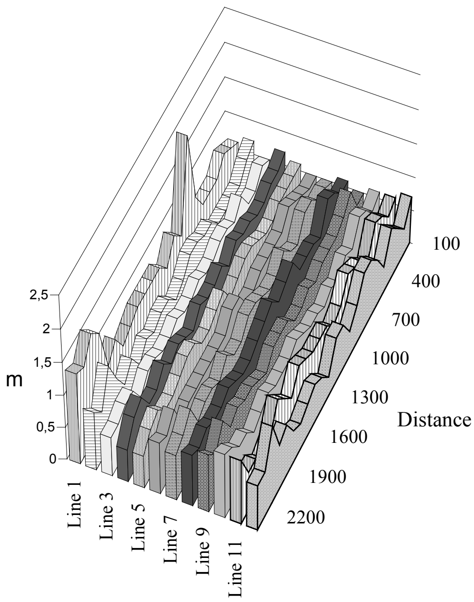


Figure 3: RMS(3-10) Fall

2.6 Roughness Criteria

There are no user costs models for airport runways used in Sweden at the present time. A fair assumption at Östersund is that the fall condition is next to adequate, i.e. the unevenness does not affect the users. By the same token another assumption would be that the spring conditions do affect user costs. Then, the limiting criteria must lie somewhere between the maximum values for the fall and the maximum values for the spring.

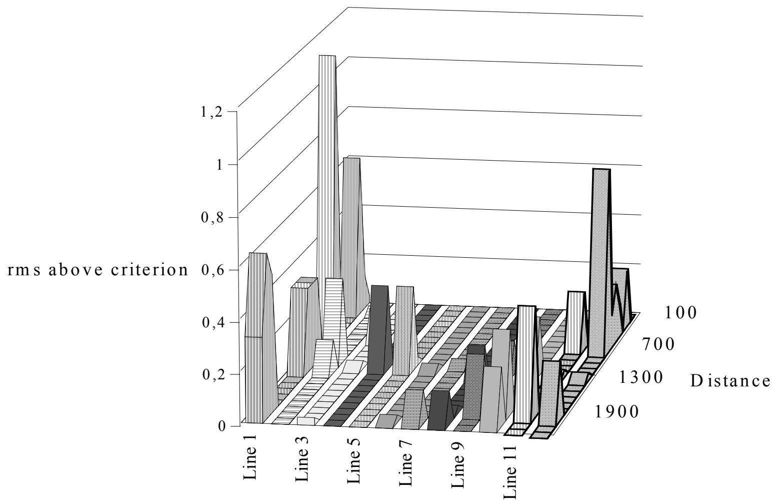


Figure 4: Failing areas as suggested

With software it is easy to construct such criteria and have them tested. The second highest maximum for any profile for the fall measurement is 1.16 at line #2. Figure 4 shows a plot with this criterion, which fails 39 sections. Even the centerline fails at two sections. If this criterion is valid 15600 square meters must be rehabilitated. An economic variant would be disregarding the lines closest to the sides. The criterion is likely to be correct from a functional point of view as it ensures that the runway is not rougher during the spring than it is during the fall for the present situation. The aircraft take-off simulation described below confirms that even the fall conditions are rougher than a typical good runway.

2.7 Aircraft Movement Simulation

The L-RST data sampled profiles were prepared for an early version of the software TAKE-OFF used by the Swedish Civil Aviation Administration. The output may be presented in the form of a diagram with four graphs; the elevation down the runway, the speed of the aircraft, the pilot station acceleration (PS) and the aircraft center of gravity acceleration (CG). A ride quality factor (RQF) is also given. The Östersund airport yields a RQF of about 1.75 in the fall and 2.2 in the spring. A typical good runway is usually below a value of .500. The PS acceleration exceeds 0.4 g in the spring for an old generation Boeing 737 aircraft as can be seen in Figure 5. Figure 6 shows the corresponding fall values yielding a maximum PS acceleration of less than 0.4. The CG values are also substantially lower than the corresponding spring numbers.

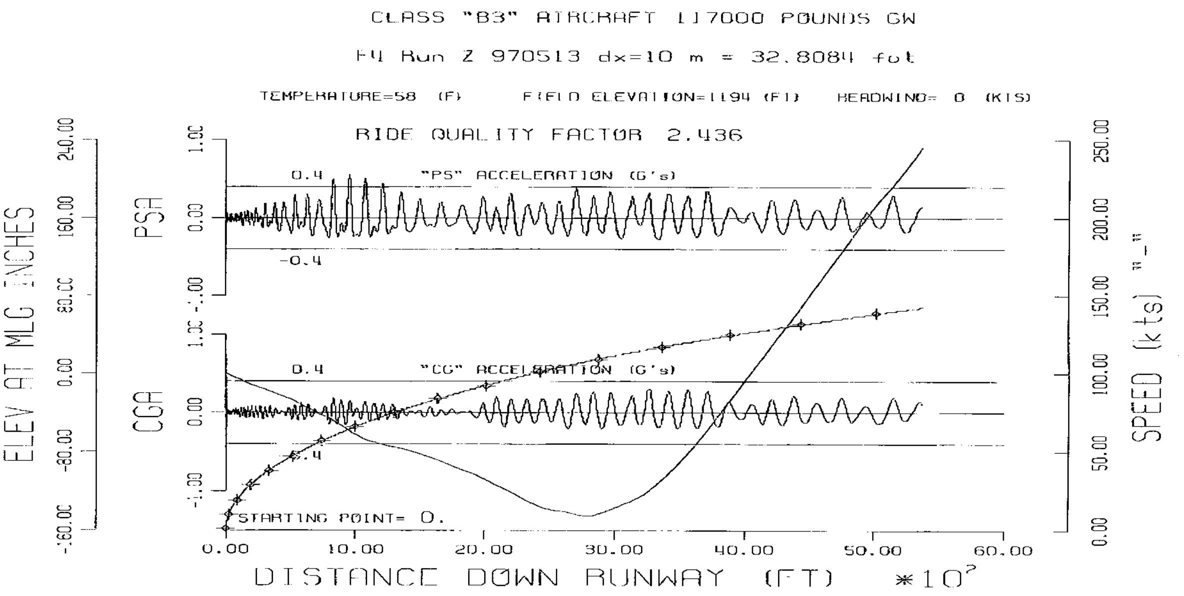


Figure 5: TAKE-OFF Graph from a springtime simulation

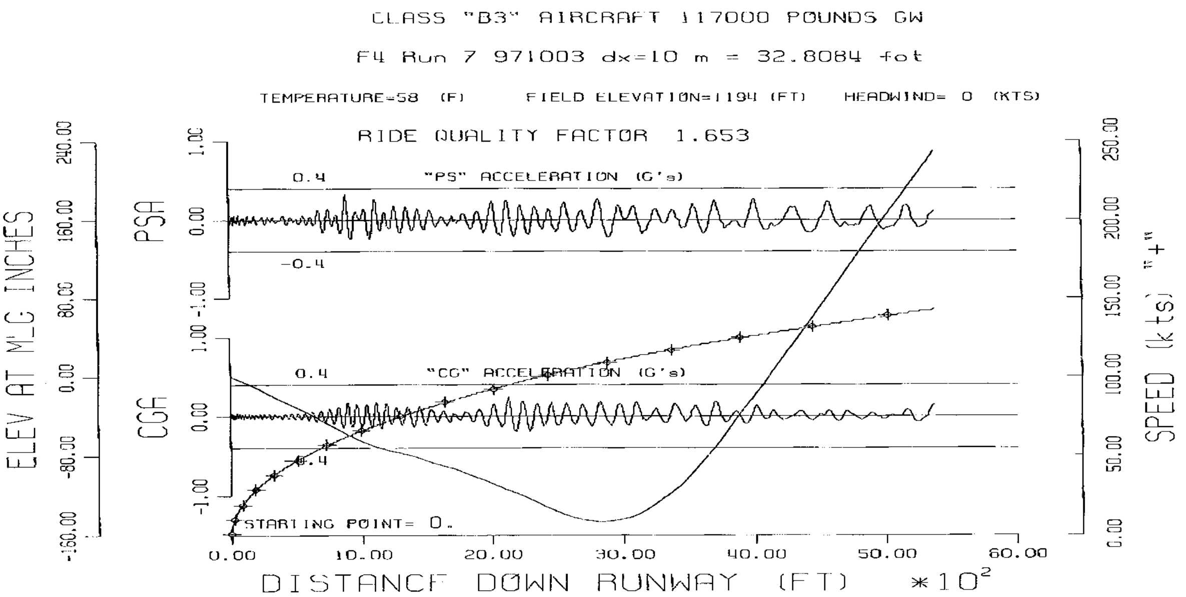


Figure 6: TAKE-OFF Graph from a fall simulation

3. ROUGH RUNWAY IN NORTHERN SWEDEN

A few years later in 2001, another rather rough military runway in Northern Sweden near the Arctic Circle was tested with an improved laser profiler recording seventeen longitudinal profiles simultaneously. In less than six hours and without any disturbance of traffic, 680 profiles were recorded covering the entire runway. From the study it was found that there was a high correlation in roughness by adjacent lines, but that the centerline profile was slightly rougher than adjacent ones. The paving joint and some meandering by the sensor over the crown may explain this fact. One profile near the centerline is shown in Figure 7. Note that 100 m down the runway there is a joint between Portland cement and asphalt concrete surfaces.

Near the ends of the runway there were many sections exceeding the 3 m ICAO straight edge criterion of 3 mm. The worst section deviated more than 10 mm and there were some sections down the middle of the runway with 4 mm deviations. An APRas take-off simulation for a light business aircraft is shown in Figure 8. The pilot seat acceleration exceeds 0.5 g:s due to the cement/asphalt concrete joint, but also further down the runway at about 300 m. See also data in Table 3.

Table 3: Data for Light Aircraft Taking off from Section 0

Distance on ground	467.9	meter	
Time on ground	16.77	seconds	
Highest ground speed	105.83	knots	
Peak Pavement Load at Main Gear:		39862	N @ 111 m
Main Landing Gear Static Load:	26868	N	
Peak Pavement Load at Nose Gear:		10184	N @ 125 m
Peak Pavement Load at Nose Gear:		5422	N
Center of Gravity Peak Acceleration:		0.52 g	@ 123 m
Pilot Station Peak Acceleration:	0.56 g	@ 314 m	
Center of Gravity RMS:	0.1205		
Pilot's Station RMS:	0.1130		
Ride Quality Factor	2.3357		

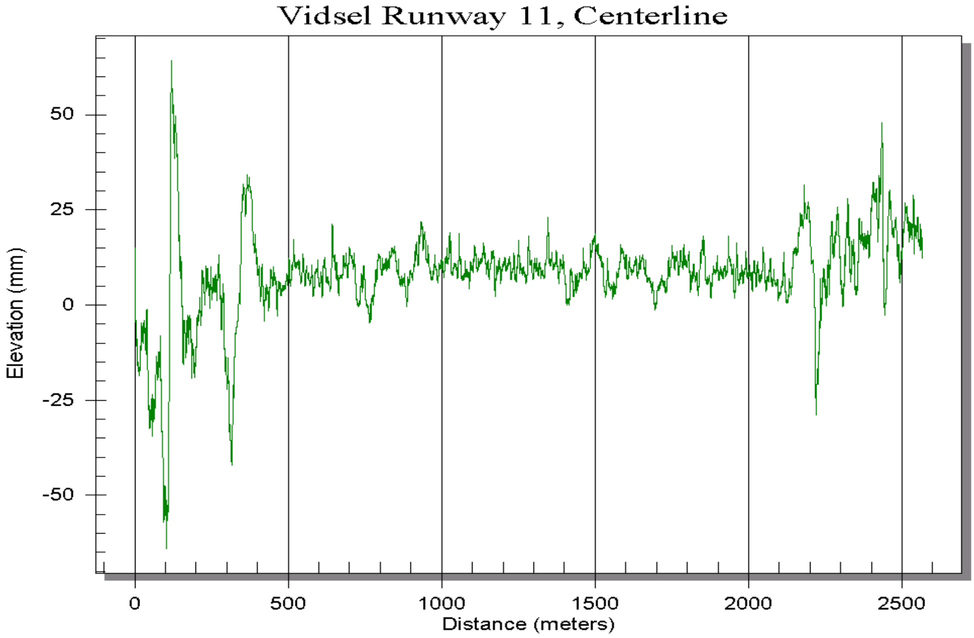


Figure 7: Runway longitudinal profile

As can be seen in Table 4 one will get forces related to vertical accelerations, which is very valuable from a comfort and thus safety point of view. From an aircraft maintenance perspective it is also very interesting to know what forces can be expected on landing gears and other parts of the vehicle. Last, but not the least for the pavement engineer it is valuable to know if the dynamic forces can be minimized somehow.

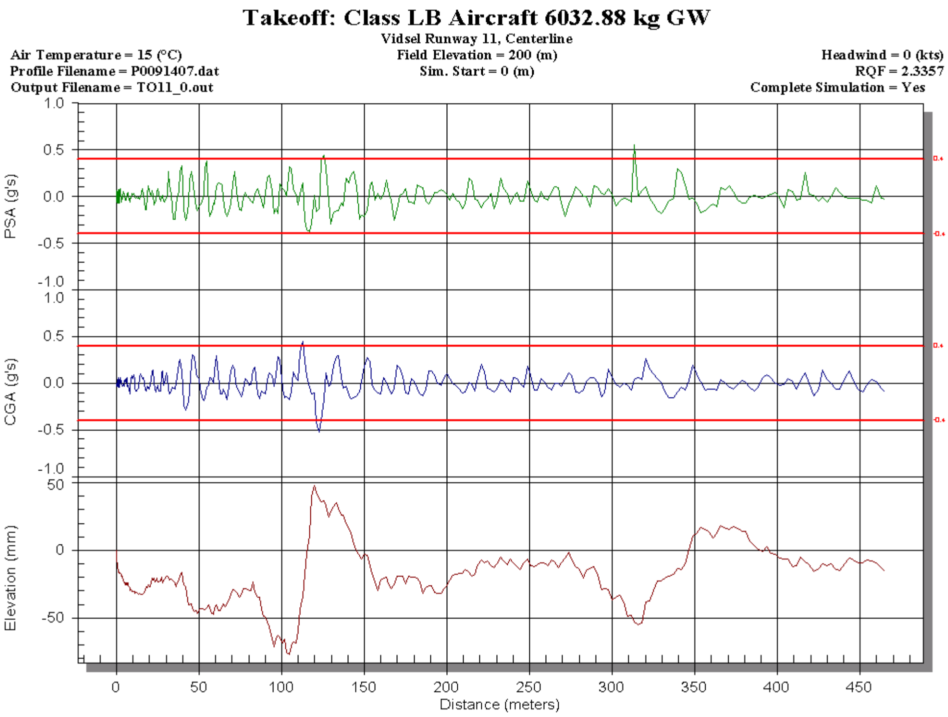


Figure 8: Simulated start at section 0 m.

The Ride Quality Factor (RQF) is related to the overall exposure to accelerations based on the average aircraft center of gravity and the pilot seat. Typically old runways usually get a rating of 1.6 on the average as in the Östersund fall situation. In this case 2.3 is not particularly good, but by moving the start to section 160 m, the value drops to 1.93 for the light business aircraft, see Figure 9.

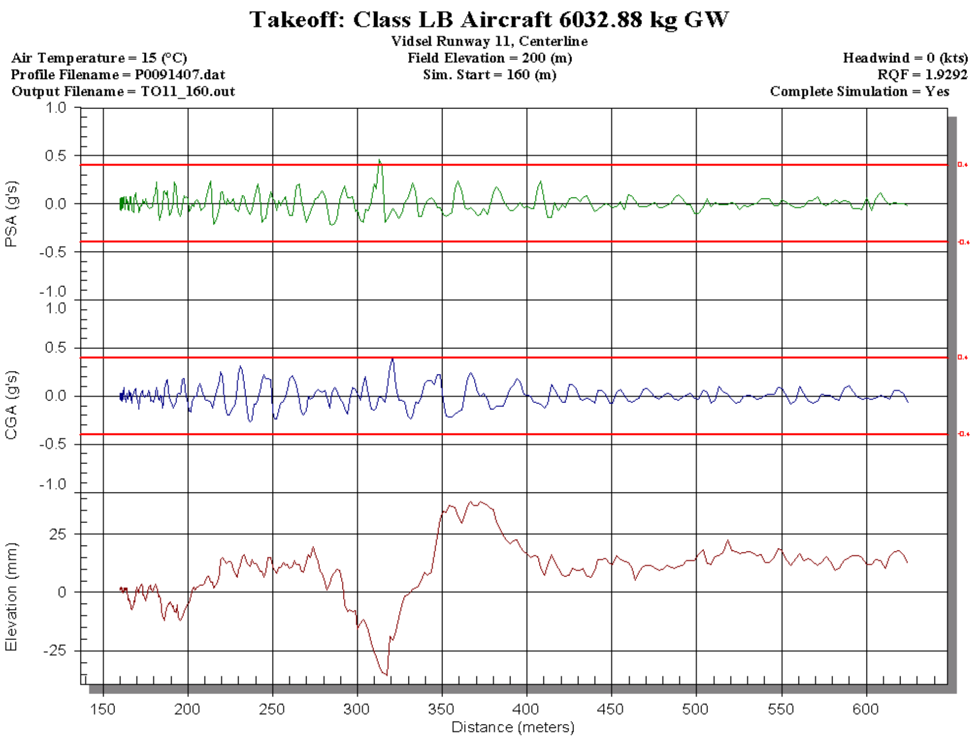


Figure 9: Starting position moved to 160 m.

The rough spot at section 330 m is nevertheless causing a .5 g acceleration at the pilot station. If the area between sections 275 – 350 is repaired by milling and filling one could look at the benefits by a new simulation. Table 4 and Figure 10 show the data for the repair. Peak accelerations drop to .30 and .22 for the CG and PS respectively. With this rather limited repair the RQF is now down to a more normal value of 1.52. As for the pavement the peak dynamic load is reduced from 39.8 to 35.9 kN. Actually, maybe not so much, but recalculated to number of passes one will get a factor of $(39.8/35.9)^4$ = 1.5. Thus, the structural life will be 50 % longer.

Table 4: Light aircraft taking off at Section 160 on repaired runway

Distance on ground	467.9	meter	
Time on ground	16.78	seconds	
Highest ground speed	105.83	knots	
Peak Pavement Load at Main Gear:		35868	N @ 246 m
Main Landing Gear Static Load:	26868	N	
Peak Pavement Load at Nose Gear:		7880	N @ 192 m
Peak Pavement Load at Nose Gear:		5422	N
Center of Gravity Peak Acceleration:		0.30 g	@ 231 m
Pilot Station Peak Acceleration:	0.22 g	@ 192 m	
Center of Gravity RMS:	0.0724		
Pilot's Station RMS:	0.0796		
Ride Quality Factor	1.5195		

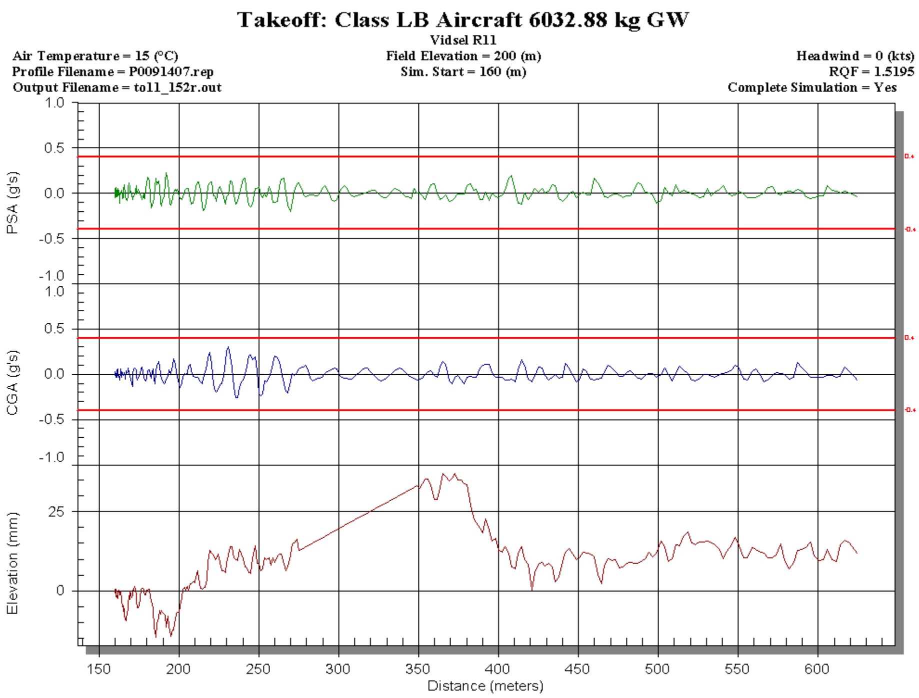
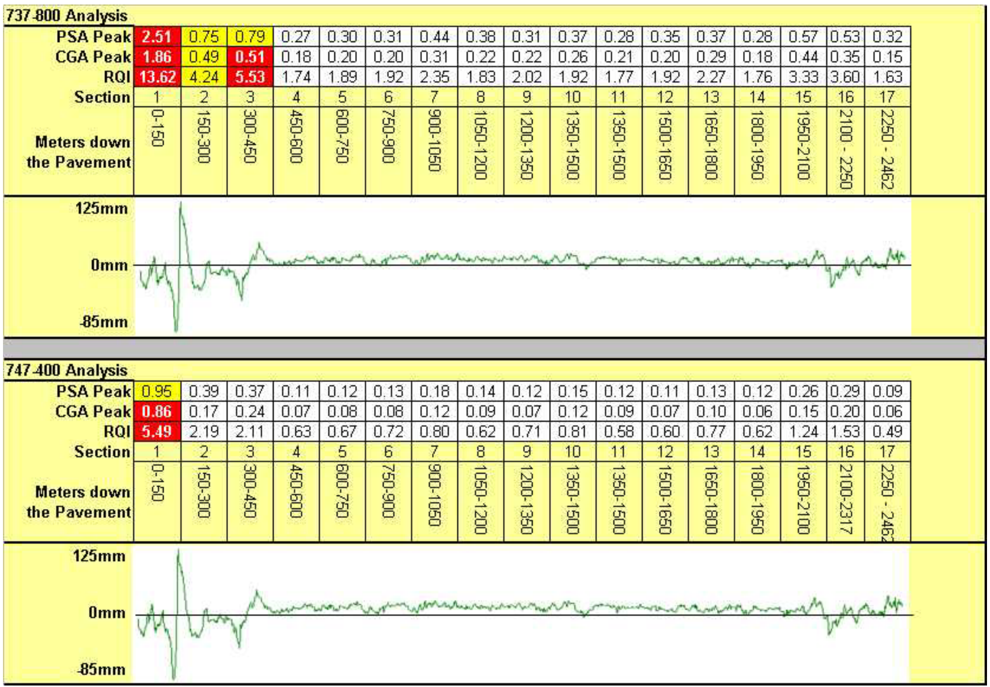


Figure 10: Simulated take-off on a repaired runway. Note Elevation at 280-345 m down the runway.

The above graphs represent only a few cases of a number of different combinations of aircraft, payload, wind speed et cetera. It would be desirable to introduce an objective rating standard of the roughness of runways. Much like the IRI for highways. The people behind TAKE-OFF and LANDING has also designed a program VSWEEP, which presents a number of combinations for a section by section rating of the various parts of the field.



737-800 Analysis

PSA Peak	2.51	0.75	0.79	0.27	0.30	0.31	0.44	0.38	0.31	0.37	0.28	0.35	0.37	0.28	0.57	0.53	0.32
CGA Peak	1.86	0.49	0.51	0.18	0.20	0.20	0.31	0.22	0.22	0.26	0.21	0.20	0.29	0.18	0.44	0.35	0.15
RQI	13.62	4.24	5.53	1.74	1.89	1.92	2.35	1.83	2.02	1.92	1.77	1.92	2.27	1.76	3.33	3.60	1.63
Section	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Meters down the Pavement	0-150	150-300	300-450	450-600	600-750	750-900	900-1050	1050-1200	1200-1350	1350-1500	1350-1500	1500-1650	1650-1800	1800-1950	1950-2100	2100 - 2250	2250 - 2462

747-400 Analysis

PSA Peak	0.95	0.39	0.37	0.11	0.12	0.13	0.18	0.14	0.12	0.15	0.12	0.11	0.13	0.12	0.26	0.29	0.09
CGA Peak	0.86	0.17	0.24	0.07	0.08	0.08	0.12	0.09	0.07	0.12	0.09	0.07	0.10	0.06	0.15	0.20	0.06
RQI	5.49	2.19	2.11	0.63	0.67	0.72	0.80	0.62	0.71	0.81	0.58	0.60	0.77	0.62	1.24	1.53	0.49
Section	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Meters down the Pavement	0-150	150-300	300-450	450-600	600-750	750-900	900-1050	1050-1200	1200-1350	1350-1500	1350-1500	1500-1650	1650-1800	1800-1950	1950-2100	2100-2317	2250 - 2462

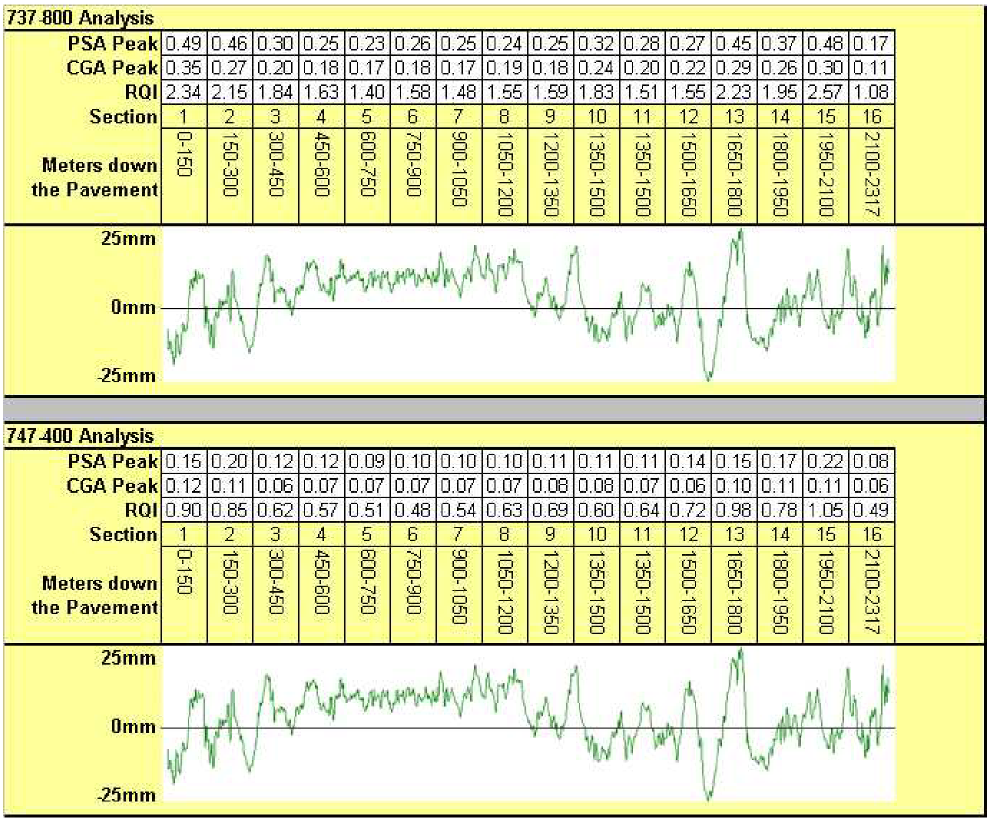
Ride Quality Index Legend:		**Peak PSA Legend:**		**Peak CGA Legend:**	
0.00 – 3.99:	None	0.00-.59	None	0.00-0.39	None
4.00 – 4.99:	Yellow	.60 – .99 G:	Yellow	.40 – .60 G:	Yellow
5.00 – Up:	Red	1.00 – Up G:	Red	.61 – Up G:	Red

Figure 11: VSWEEP of Rough Airfield near Artic Circle.

For a given aircraft chosen by the user, the program performs a velocity sweep (from 20 knots to start of rotation) on each section of pavement until it reaches the end of the profile. This action ensures that the entire pavement is analyzed at all possible speeds. This process will identify the aircraft's response at each speed in the sweep, thereby identifying the peak response and at what speed the response occurred. As can be seen in Figure 11, the first 450 m of the runway is rated bad, especially for the smaller 737-800 aircraft presented in the top part of the diagram. (The response of a larger 747-400 is also shown in the bottom part). Note that the Ride Quality Index is not exactly the same as the Ride Quality Factor, which was used for the particular case.

3.1 Drainage Application

For comparison a VSWEEP was also done at another airport in an area with next to negligible frost actions and thus with a much better RQF, see Figure 12. Note that the vertical scale is different from the rough airfield. For the 747 aircraft the highest RQI is 1.05 where a crossing runway causes some roughness.



737-800 Analysis

Section	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
PSA Peak	0.49	0.46	0.30	0.25	0.23	0.26	0.25	0.24	0.25	0.32	0.28	0.27	0.45	0.37	0.48	0.17
CGA Peak	0.35	0.27	0.20	0.18	0.17	0.18	0.17	0.19	0.18	0.24	0.20	0.22	0.29	0.26	0.30	0.11
RQI	2.34	2.15	1.84	1.63	1.40	1.58	1.48	1.55	1.59	1.83	1.51	1.55	2.23	1.95	2.57	1.08
Meters down the Pavement	0-150	150-300	300-450	450-600	600-750	750-900	900-1050	1050-1200	1200-1350	1350-1500	1350-1500	1500-1650	1650-1800	1800-1950	1950-2100	2100-2317

747-400 Analysis

Section	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
PSA Peak	0.15	0.20	0.12	0.12	0.09	0.10	0.10	0.10	0.11	0.11	0.11	0.14	0.15	0.17	0.22	0.08
CGA Peak	0.12	0.11	0.06	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.07	0.06	0.10	0.11	0.11	0.06
RQI	0.90	0.85	0.62	0.57	0.51	0.48	0.54	0.63	0.69	0.60	0.64	0.72	0.98	0.78	1.05	0.49
Meters down the Pavement	0-150	150-300	300-450	450-600	600-750	750-900	900-1050	1050-1200	1200-1350	1350-1500	1350-1500	1500-1650	1650-1800	1800-1950	1950-2100	2100-2317

Ride Quality Index Legend:		**Peak PSA Legend:**		**Peak CGA Legend:**	
0.00 – 3.99:	None	0.00-.59	None	0.00-0.39	None
4.00 – 4.99:	Yellow	.60 – .99 G:	Yellow	.40 – .60 G:	Yellow
5.00 – Up:	Red	1.00 – Up G:	Red	.61 – Up G:	Red

Figure 12: VSWEEP of a smooth field.

As obvious runway roughness is not a problem here, rather at this site there is a concern of insufficient surface water drainage as a result of the cross fall changing sides. By combining eight runs of seventeen longitudinal profiles each, a grid was set up for a CAD program, Mill & Fill. This method has been described earlier and has become quite common for highways in Sweden, with an excellent result in improving roughness properties. A project was previously done for a taxiway at this airport, (Lenngren, 1999).

Figure 13 shows the right side of runway 01 at a section with problems of standing water. The pavement engineer can in the computer look at several alternatives of solving the problem, and choose the most economical alternative. At all times it is possible to simulate take-off and landings so that profiles do not affect aircraft operations negatively.

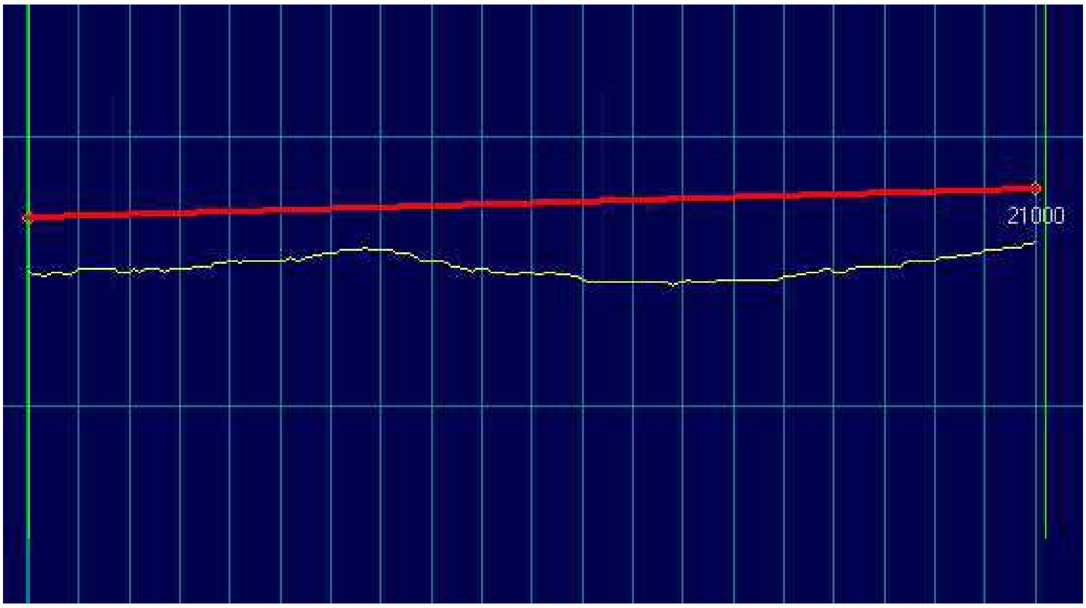


Figure 13: Cross-section of right side of Runway 19 as seen in CAD program. Thin line is original surface. Straight bold line is the new design. Vertical lines are 1m apart. Horizontal lines 1dm.

4. DISCUSSION

The present paper shows that there are relevant parameters for describing different roughness phenomena and that some of them may be very much related to user costs. It is now possible for the airport community to address pavement management issues in the same way as road authorities do, i.e. not only consider maintenance costs but also the user costs. With modern profilometers it is fairly easy to collect data in a very short time. The equipment may not have to be as sophisticated as the one used in the present study, capable of presenting a plethora of parameters. A number of different profilers are listed in the literature, (Shahin, 1994). There are portable variants consisting of one single laser unit and an accelerometer that can be attached to any vehicle, e.g. a friction tester. With such equipment, larger airports could have their roughness checked on a regular schedule. Thus, very valuable data could be obtained for planning ahead. Further, the data may contribute to a more efficient aircraft operations schedule for the large airport. E.g. traffic could be diverted to the runways and taxiways rendering the least user costs for the time being. Last, but not least the data would also be used for better airport pavement management. Further research must be addressed to the needs of user and models must be found that will reflect that need. Since speed is varying quite a bit along the runway different criteria will apply for different parts of it. Wavelengths up to 100 m may be of interest. The platform pitch measuring lasers seem to be a viable method for including very long wavelengths. The method was adequate for the three runways presented in the present paper. However, a thorough validation must be undertaken in further studies. Alternatively, on surfaces that can be closed for some time, a feasible method is obtaining the data by rod and level since these long wavelengths are very unlikely to change much over time. Programs such as TAKE-OFF & LANDING would be of valuable help in establishing the criteria. The airport pavement management community around the world would also welcome aircraft manufacturer's recommendations about tolerable roughness and user costs associated to it. The intermediate wavelength band affected by frost heave may influence tire behavior quite substantially. It may influence the safety since the tire-pavement interaction may be an issue, especially as the trend is towards higher tire pressures.

5. CONCLUSIONS

Fast profiling equipment has helped highway pavement engineers worldwide to adapt to user cost driven management systems. Such thinking has improved quality cost and assurance in the transportation sector as well as a better product for less money.
For airports profilers could also be used but the simulation of motions must be adapted to varying speed and traffic situations.

Typical profiler applications for airfields include:

- RQF as user cost calculations.
- Wear and tear of aircraft.
- Geometrical design
- Structural design
- Seasonal variation studies

By investigating different wavelength intervals it was found that the 3-meter fixed straightedge guideline criterion was little affected by severe frost heave at the Östersund airport. The IRI showed a significant difference, but some other wavelength intervals were more predominant in showing a seasonal change of the roughness. The different wavelength bands can be attributed to different types of roughness induced in different types of aircraft and also different parts of a given aircraft. It would not be too difficult to establish criteria for how much deviation should be tolerated for different parts of the runway and taxiway systems. Finally, by looking at the different wavelengths one would also get a better indication of the cost for rehabilitation than what a single roughness value like the IRI would produce. Future work for establishing roughness criteria should aim at gathering data over the entire year, especially important in cold climates. The simulation procedures look very promising in establishing functional criteria for airfields. Once the method gets accepted, a validation procedure with instrumented aircrafts should take place.

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