ABOUT TRANSVERSE SLOPE AND DRAINAGE OF THE RUNWAY SURFACE

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Abstract: *In order to operate safely on the road surface, the macrotexture and the transverse slope of the runway have important roles and must be analyzed as an interdependent system. In the case of wet surfaces, in conditions of inadequate drainage, the risk of aquaplaning is greater. Proper drainage, system optimization, must ensure macrotexture and transverse slope characteristics that allow water or contaminants to drain from the surface, to prevent stationary accumulations of liquids. The paper deals with a case study regarding the influence of the transverse slope value and the mean depth of the macrotexture on the drainage characteristics, on a wet surface, and the impact on the safety of operations.*

Keywords: *transverse slope, macrotexture, drainage, slope*

1. Introduction

The slopes of a runway, together with the macrotexture characteristics, contribute to the optimization of surface drainage and the avoidance of the accumulation of standing water. Longitudinal and transverse slopes should be sufficient to prevent the accumulation of water on the surface and to ensure rapid drainage of surface water.

The slopes of a runway are intended to prevent the accumulation of water (or possible fluid contaminant) on the surface and to facilitate the rapid drainage of surface water (or a possible contaminant fluid). The drainage of water (or a possible contaminant fluid) is facilitated by an appropriate combination of longitudinal and transverse slopes and may also be aided by the grooving of the runway surface, [EASA,2025].

Rapid drainage is a primary safety element in runway design, construction and maintenance. The objective of drainage is to minimize the thickness of the surface water film by draining the water away from the asphalt surface of the runway and, in particular, away from the path of the aircraft tire.

To ensure rapid water drainage, it is recommended that the runway surface be domed, if possible. In the case of a domed surface, the transverse slopes on both sides of the centerline should be symmetrical, [PETA,2022].

On wet runways, in crosswind conditions, the risk of aquaplaning due to poor drainage is increased.

The two types of water drainage encountered in the case study are natural drainage of the water layer on the runway, which allows it to be collected in drainage channels on the sides of the runway, and dynamic water drainage, which involves the evacuation of water from under a moving tire, outside the tire-tread contact area.

Dynamic drainage is achieved by the texture incorporated into the runway surface. The tire, when rolling, increases the water pressure and squeezes the water from the drainage channels provided by the texture. The dynamic drainage of the tire-ground contact patch can be improved by adding transverse grooves, provided that they are subject to rigorous maintenance, [EASA,2025].

Numerous predictive models for water layer thickness have been found in the literature:

empirical, statistical and complex models that provide relatively accurate predictions. Those based on empirical data or equations have obvious limitations, [Xiao, 2023].

[Kang Zhao, 2024] states that these limitations include the neglect of factors such as road texture and permeability, limited applicability associated with local empirical data, the inadequacy of using fixed values of precipitation intensity to capture the diversity of climatic environments, and constraints in considering different types of road surfaces in water layer thickness calculations.

The analysis used a simplified model, chosen precisely due to the limited availability of experimental data. The model, presented below, allows for obtaining relevant results under the conditions of existing information.

2. About transverse slope of the runways

The runways transverse slopes have essential roles: ensuring drainage (they allow rapid drainage of rainwater or due to snowmelt, preventing accumulations and puddles) and operational safety (they reduce the risk of aquaplaning, maintaining conditions within acceptable limits for landing and stopping the aircraft).

Based on the recommendations [EASA,2025], which state that the main purpose of transverse slopes is to ensure efficient drainage of water from the runway surface, the transverse slope for the type of surface analyzed should be between 1% and 1.5%.

The analyzed surface is an asphalt carpet type, a flexible airport runway used for landing, taking off and taxiing of aircraft.

3. About the thickness of the water layer depending on the slope and macrotexture

The mathematical relationship, [Gerthofert,2014], is based on an elementary model, completed and improved by field experiments. This model allows the characterization of the thickness of the water film on the road, considering the macrotexture and measurement uncertainties.

The model used is the model [Gothié, 2001], where the macrotexture descriptor is updated according to (ISO, 1997). The formula used is:

$$W = 0{,}29MPD^{0{,}4}\frac{(IL)^{0{,}4}}{p^{0{,}3}} - 1{,}1MPD + 0{,}30 \qquad (1)$$

W is the thickness of the water film (mm), *I* is the rainfall intensity (mm/h), *L* is the length of the flow line (m), *p* is the slope (%) and *MPD* (Mean Profile Depth is the average profile depth (mm), i.e. the average value of the characteristic profile depths measured over a certain length interval).

The value of 0.30 mm represents an empirical calibration constant, whose role is to correct the deviations of the model from the real measurements (especially for small values of the MPD macrotexture and low rainfall intensities) [Gallaway, 1972].

In the studied case, an airport runway: L is 22.5 m (half the width of the analyzed surface); slope of 1 %; rainfall intensity has values between 2.5 mm and 7.6 mm; the average macrotexture depth is interpreted from the measured values available from the airport authority for 10 meters left of the runway centerline.

Figure 1 is a schematic representation of the runway cross slope with the crest (centerline of the runway) and the edge (side) of the runway as references.

4. About the airport runway transverse slope

The influence of the transverse slope of the runway is significant because if it is inadequate, it contributes negatively and allows the accumulation of water, de-icing fluid on the runway, which leads to a decrease in the values of the friction coefficient in the tire-runway contact.

In figure 1 is a schematic representation of the transverse slope of the runway having as references the crest (centerline of the runway) and the edge (side) of the runway.

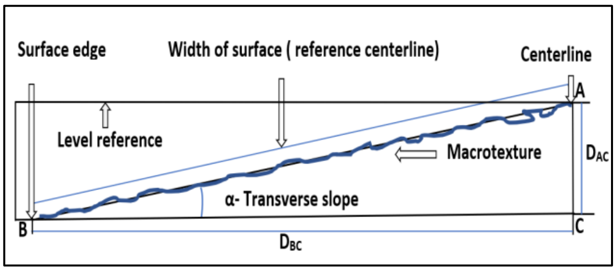

Figure 1*: Schematic representation on transverse slope of the runway surface*

The horizontal distance, BC is the length of the orthogonal projection of the segment AB. The segment AB is half the width of the runway, and in the studied case it is 22.5 m.

The difference in level is the vertical distance between the flat surfaces of the two points A (the intersection points of the runway slope and the shoulder slope) and C (the reference used for the runway axis, where the slope begins). The runway slope is the inclination of the line joining the two points B (the edge of the runway) and A (the runway axis) with respect to the horizontal, expressed by the ratio of the difference in level to the horizontal distance of the two points:

$$P_{AB} = \frac{AC}{BC} \quad (2)$$

In fact, the slope of the runway, which is expressed in percentage, is the trigonometric tangent of the vertical angle α:

$$P_{AB}\,\% = \frac{D_{AC}}{D_{BC}} = \tan\alpha \cdot 100 \quad (3)$$

The primary data on which the slope analysis is based are presented in figure 2, the runway slope, in the analyzed case, is 1% and 2%.

It is noted that in the current configuration the transverse slope is 1% over the entire width of the runway and 2% in the area of the runway shoulders.

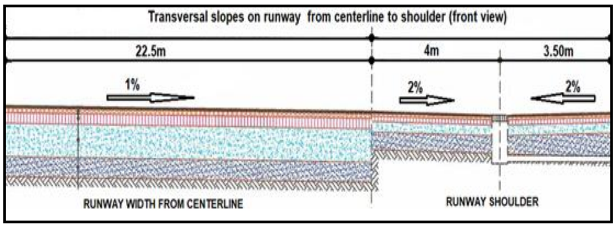

Figure 2: *Transvers slope on runway from centerline to shoulder (source: airport authority)*

5. Data analysis and interpretation

According to [AASHTO, 1992], longitudinal slope (changes in longitudinal slope) does not have a significant effect on the thickness of the water film on the runway surface compared to the transverse slope. To determine the main influencing factors, formula 1 was used.

Next, we analyze how the intensity of precipitation influences the thickness of the water film on the surface. For this, the reference thresholds [Ketabdari,2021] for light rain (rainfall rate < 2.5 mm/h) and moderate rain (2.5 mm/h < rainfall rate < 7.6 mm/h) were considered.

In figure 3, it is observed that with increasing precipitation intensity (*I*), the thickness of the water film (*W*) also increases. The primary data were the measured values of the MPD, with a constant flow length of 22.5 m (half the width of the runway) and at a slope of 2% (from the airport data). Thus, increasing rainfall intensity causes the increase of *W*, but not linearly, the curve flattens at high values.

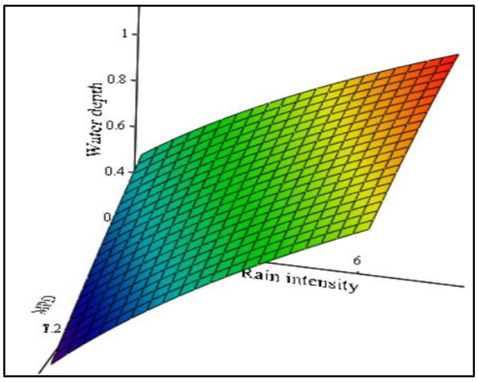

Figure 3: *Comparison of precipitation intensity/water film thickness*

To observe the influence of slope (*p*) on the thickness of the water film, figure 4, measured data from the MPD were used, with a constant flow length of 22.5 m, average rainfall intensity of 4.5 mm/h and a slope varying between 1-5%.

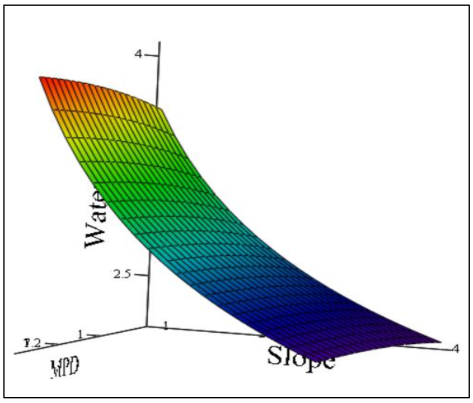

Figure 4: *Comparison of slope/water film thickness*

Thus, it is observed that a higher slope leads to a decrease in the thickness of the water film.

The analysis of the influence of the low slope, for *p* between 0-1%, figure 5, highlights on the graph, a "bell" curve. The behavior of the water film thickness can be interpreted as follows: at low values of MPD the thickness of the water layer increases, reaches a maximum, then decreases at large macrotextures. Thus, on smooth surfaces water accumulates more easily and when the texture becomes rougher, the increase in macrotexture improves the drainage and the thickness of the water film decreases. As the slope increases, the surface tilts and the thickness of the water film decreases.

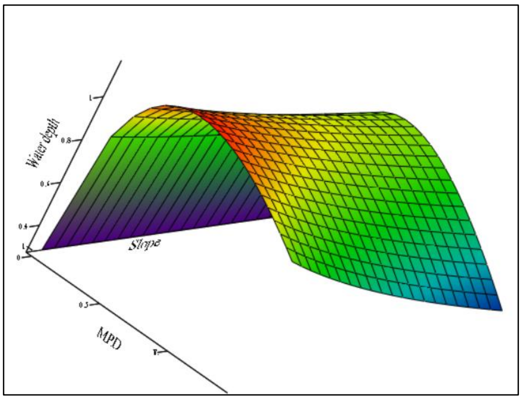

Figure 5: *Comparative low slope (0-1%) / water film thickness*

In conclusion, the reduction of the water layer is done either by increasing the slope or by a greater macrotexture that allows the drainage of water from the surface.

Looking at the influence of the length of the flow line (*L* which has so far been treated as constant), in figure 6, it is observed that this introduces a behavior almost similar to the intensity of the rain, an increase in *L* leads to an increase in the thickness of the water film.

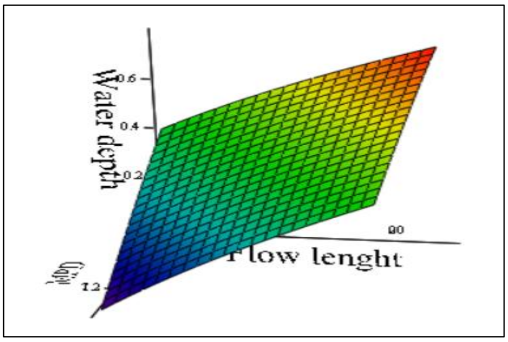

Figure 6: *Comparative flow length/water film thickness*

If up to now the variables and their influence on the water film thickness were the intensity of precipitation, the slope of the runway and the length of the flow, we will now analyze it from the perspective of MPD.

The term appears in two places in the formula used: ($MPD^{0.4}$), with an increasing effect and (−1.1MPD) with a reducing effect. This aspect suggests a nonlinear and contradictory effect: at low values of MPD (the case of smooth surfaces), the water depth *W* increases, but at high values (rough surfaces), the term (−1.1MPD) becomes dominant and reduces the accumulation of water.

In figure 7, the representation is made for low values of MPD (0-0.4), a less rough/smoother surface, with L-22.5 m, slope 1-2 %, to simulate the behavior of the water film thickness depending on the quality of the surface, smoother or rougher.

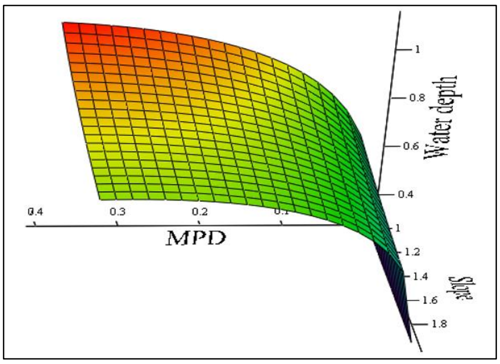

Figure 7: *Comparative variation of MPD and low slope/water film thickness*

For small values of MPD (0.1–0.4 mm, smooth surfaces) the water depth is large. As the MPD increases, the water layer decreases. At *p* of 1%, water accumulates more, at *p* of 2% the water layer decreases visibly. In conclusion, for a small MPD and small slope, the thickness of the water film tends to high values (critical case for aquaplaning).

Next, a confirmation and correlation of the data from the calculations with the reality on the ground, on the airport runway, was carried out by a visual check of the conditions present on the runway 10 meters laterally from the centerline. The weather conditions in which the field visit was carried out, according to METAR (regular airfield weather observation message) were moderate rain, temperature of 12 degrees Celsius.

It was observed that area, with a slope of 1% and macrotexture below 1 mm (data from the airport), does not allow a similar drainage to the other areas (for example, the area near the runway centerline), drainage that should allow the efficient flow of water towards the runway shoulder to the collection channels.

The macrotexture on the 10-meter line is reduced due to the chemical effect of the substances used (accumulations towards the sides of runway) when deicing the runway surface, of the turbo blowers and brushes used to remove snow, or by the water draining from the surface towards the extremities, the water carrying impurities, dust, pebbles, liquid towards the sides of the runway.

The second field observation focused on the influence of the surface slope on the thickness of the water film generated by rain. Two lines (2 meters and 10 meters) were chosen for a comparative analysis because the two surfaces present significant differences.

It is clearly observed in the field that in the area where the slope is higher, in this case 2% (the shoulder areas), the water drained faster and the surface in some places is completely drained.

According to [Ketabdari,2021], who made a correlation between the results regarding the average thickness of the water film in relation to the macrotexture characteristics and the transverse slope of the runway, it resulted that a transverse slope of 1.5% at a macrotexture of 1 mm is the optimal degree in decreasing the thickness of the water film under the aircraft tires, thus not compromising the aircraft's ground maneuvering ability.

Field observations and analyses on the 10-meter line area, where the predominant macrotexture values are below 1 mm and the designed slope is 1%, identified areas where water does not drain completely or uniformly to the collection channels on the shoulder.

Considering the 1% value of the transverse slope and comparing with the results obtained from the analysis [Ketabdari,2021], it can be interpreted that a higher transverse slope would allow for more efficient water drainage from the runway.

Following the correlation between theoretical calculations and field validation of the results, it is observed that the runway slope is the main factor influencing the water flow velocity, while the flow length is determined by the surface macrotexture.

Thus, an increase in the slope from 1% to 1.5-2%, correlated with an appropriate macrotexture, by eliminating deposits covering the surface voids (which reduce the average depth of the macrotexture below 1 mm), will implicitly lead to a decrease in the water stagnation time on the surface and thus to the optimization of the friction coefficient.

An adequate macrotexture value above 1 mm correlated with a slope of 1.5% (in the treated case being 1% to) would lead to more efficient surface drainage. However, the various irregularities on the surface that allow stationary accumulations of water must also be considered.

Macrotexture essentially ensures the drainage of water from the runway surface, a low macrotexture can lead, in the case of a road surface subjected to precipitation (rain), to a significant decrease in the tire-road friction coefficient, [Nazarie,2024].

Conclusions

- Low macrotexture means that water cannot be effectively channeled towards the runway shoulder.
- Although a 1% slope is considered minimal for drainage, it has been observed that this may not be effective, especially in combination with low macrotexture.
- A low slope allows water to drain but increases stagnation time and the risk of forming standing water on the runway. If there are also deviations in execution, a 1% slope can become ineffective in some areas of the runway surface
- Low macrotexture and a low slope lead to stationary water accumulations that increase the risk of aquaplaning, decrease the friction coefficient and affect the safety of operations.
- Low macrotexture, low slope, high precipitation intensities lead to the formation of a maximum water layer (the riskiest combination).
- High macrotexture and a high slope however lead to the formation of a minimum water layer, even in more intense rain.
- The slope of the runway is the main factor influencing the speed of water flow, while the length of the flow is determined by the macrotexture of the surface.

In conclusion, the reduction of the water layer is done either by increasing the slope or by a large macrotexture, which allows drainage, the determination of the optimal values being carried out depending on the operating requirements of the runway, the operational and functional purpose.

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