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The information contained herein is based on ICAO Compliance Requirements

UPAVED RUNWAY & AIRSTRIP ICAO COMPLIANCE REQUIREMENTS & EXPLANATIONS

A runway/airstrip is an essential element of any airport/airfield, and it significantly influences the safety of an aircraft that uses it. A typical flight includes various phases, but landings and take-offs are considered as the most crucial phases of the flight. An improper landing or take-off may result in serious implications for safety of the aircraft and its occupants, if the runway/airstrip condition is compromised.

An aircraft imposes a tremendous load on a runway/airstrip pavement during landing phase that causes deflection of the pavement. Consequently, the airstrip/runway design and performance requirements are largely affected by the potential deflection. A critical review of the relevant literature indicates that the study of aircraft-airstrip interaction has been a challenging problem for runway/airstrip designers, airport/airfield operators, and researchers.

Airports as many other organizations need to provide maintenance to the facilities and assets to ensure serviceability and operational safety for the business continuity and services. No matter the size of the airport or aerodrome, runways are key infrastructures requiring their surfaces to be kept in optimal conditions in order to maintain continuous and safe aircraft operations during landing and departing. Airports may establish large or small maintenance organizations to cope with this operational responsibility.

ICAO Annex 14, Volume 1, Chapter 1, Section 1.4 on Certification of Aerodromes stipulates the requirements. It also emphasizes the obligations and responsibilities of the Civil Aviation Regulating Authorities (regulator) and the airfield owner or operator.

Refer to the chart below of Codes for Runway Width Requirements based on Aircraft Wingspan

Gravel Runway ICAO Compliance Requirements and Explanation

Outer Main Gear Wheel Span (OMGWS)				
Code Number	Up to but not including 4,5 m	4,5 m up to but not including 6 m	6 m up to but not including 9 m	9 m but not including 15 m
1	18 m	18 m	23 m	---
2	23 m	23 m	30 m	---
3	30 m	30 m	30 m	45 m
4	---	---	45 m	45 m

Code Letter	Airplane Wingspan	Typical Airplanes
A	< 15 m	Piper PA31 Navajo, Cessna 404 Titan
B	15 m but < 24 m	Bombardier Regional Jet CRJ-200
C	24 m but < 36m	ATR42-500, Boeing 737-700, Airbus A320
D	36 m but < 52m	Boeing 767-300
E	52 m but < 65m	Boeing 777/787, A330
F	65 m but < 80m	Boeing 747, Airbus A380

Corresponding Pavement Strength Requirements based on Aircraft Code Classification

Strength	Description	Letter
High	For rigid pavements, k = 150 MN/m3 (for all values above 120 MN/m3). For flexible pavements, CBR = 15 (for all values above 13).	A
Medium	For rigid pavements, k = 80 MN/m3 (for all values between 60 and 120 MN/m3). For flexible pavements, CBR = 10 (for all values between 8 and 13).	B
Low	For rigid pavements, k = 40 MN/m3 (for all values between 25 and 60 MN/m3). For flexible pavements, CBR = 6 (for all values between 4 and 8).	C
Ultra low	For rigid pavements, k = 20 MN/m3 (for all values below 25 MN/m3). For flexible pavements, CBR = 3 (for all values below 4).	D

Definitions

• **Unpaved Surface**: A surface, intended for aircraft operations, composed of unbound or natural materials. Unpaved surfaces may include gravel, coral, sand, clay, hard packed soil mixtures, grass, turf or sod. (Note: Unpaved surfaces are also referred to within the aviation industry as « Unimproved Airstrips »)

• **Unpaved Airstrip**: An airstrip pavement constructed with an unpaved surface.

• **Unprepared Surface**: Any naturally occurring surface used as an airstrip that has not been altered by man

The various surface types

There are various pavement surface types used to describe airstrip pavement. The following descriptions are provided in the Boeing airport compatibility manual:

Macadam: (sometimes called tarmacadam, or tarmac) - Uniformly sized stones rolled or compacted in-place, and usually sealed by an asphalt treatment that penetrates into the uppermost portion of the surface or coated with tar or bitumen. Usually, such surfaces are thin by typical airport standards, on the order of 2 to 5 centimeters thick.

Gravel airstrip - An airstrip, typically constructed of a mixture of compacted soils and stones or laterite, the latter also being referred to as “laterite airstrip”, with a surface that is not bound by any additives (neither asphaltic nor cementitious). Such airstrips are classified as "unpaved" and are sometimes referred to as "unimproved". A grass airstrip usually does not qualify as a gravel airstrip.

Seal Coat - This type of runway is usually an unpaved (gravel or laterite) airstrip, the surface of which has been treated with a sealant (usually asphaltic or resinous) to create a well-textured, waterproof surface that typically has a total thickness of less than one to two centimeters. Such surfaces generally stand up well to high tire pressures or high wheel loads. If the surface is unbroken, the airstrip is considered paved or hard surfaced.

Slurry Seal - A mixture of well-graded fine aggregate, mineral filler, emulsified asphalt and water, applied to a runway or an apron as a surface treatment. Slurry seals are generally only applied to previously paved surfaces.

Unpaved airstrip surfaces can be subject to significant variations in their strength and surface characteristics because of climatic effects and the effects of aircraft operations.

Unpaved airstrips can achieve their design strength and surface characteristics when maintained properly and not subject to excessive moisture. Gravel and laterite surfaces deteriorate with time and under repeated traffic loadings. The most common defects occurring with unpaved surfaces are ruts, depressions, potholes, soft spots and loss of aggregates. Periodic grading, compaction and addition of new material are required to maintain the integrity of the gravel surface and to ensure the safe operation of aircraft.

Unpaved airstrip surfaces are typically non-homogeneous in composition and may contain various types of soils. Soil classification is used to predict the probable behaviour of soils under the influence of frost and moisture.

• **The California bearing ratio (CBR)** provides a measure of the ability of an unpaved surface to resist shearing under aircraft loads. CBR is the ratio of the load bearing capability of a given sample of soil compared to that of crushed limestone. The CBR of a given soil test is expressed as a percentage ranging from 0% to 100% or a whole number ranging from 0 to 100.

• CBR should be considered an index of airstrip surface strength as opposed to an absolute or true value of shear strength, because of the dependence of the CBR value on the measuring device used

Definition of ACN-PCN

Aircraft classification number (ACN): defined as a number expressing the relative effect of an airplane of a given weight on a pavement structure for a specified standard subgrade strength based on a specified standard. Use of the standardized reporting method for pavement strength applies only to pavement intended for complex aircraft operations

• **Aircraft classification number (ACN):** defined as a number expressing the relative effect of an airplane of a given weight on a pavement structure for a specified standard subgrade strength based on a specified standard.

• **Pavement classification number (PCN):** is defined as a number expressing the bearing strength of a pavement for unrestricted operations.

The ACN-PCN system is a method used solely for reporting the relative strength of pavement, based upon which airport operators are able to determine whether operation of their airplanes is acceptable. It is not intended as a pavement design method or a pavement assessment procedure, nor does it restrict the methodology used to design and assess a pavement structure.

<u>WEATHER AND WEAR EFFECTS ON UNPAVED AIRSTRIPS</u>

Conditions of excessive moisture, such as those found during heavy precipitation and poor drainage can result in a significant degradation in airstrip surface strength.

The degradation in surface strength may be enough to limit or completely restrict operational use.

The following factors can adversely affect unpaved airstrips:

• Loss of material resulting in bare spots and sub-grade material appearing on the surface.

• Accumulation of loose, non-cohesive aggregates on the surface because of material segregation.

• Formation of ruts in wheel paths.

• Persistence of damp or wet areas because of poor surface drainage.

• Soft areas during wet conditions.

• Airstrip roughness or longitudinal unevenness (waviness); and

• Vegetation growth.

EFFECTS OF UNPAVED AIRSTRIPS ON AIRCRAFT PERFORMANCE

• Increased takeoff distance due to the increased rolling resistance (caused by the deflection of the surface under the load of the aircraft).

• Increased stopping distance due to reduced braking performance.

• Increased accelerated stop distances (in case of rejected take off) due to the factors mentioned above.

• Degraded handling on the ground (during take-off and landing roll as well as ground maneuvering. The use of nosewheel steering may be necessary for improved handling, or in some cases prohibited if incompatible with unpaved surfaces.

• Procedures and equipment necessary to protect an aircraft may also have an adverse effect on takeoff and landing performance. The procedures usually limit pilot intervention and most protection equipment (e.g. shields, deflectors, etc.) impacts aircraft aerodynamics and weight.

AIRCRAFT PROTECTION FROM DAMAGE

Protection of aircraft components is necessary so that operators can safely use aircraft on unpaved surfaces. Operators typically achieve this through special procedures and equipment, e.g.:

• Gradual application of thrust or power to minimize the ingestion of materials by engines or damage to propellers.

• Limited or prohibited use of reverse thrust.

• Configuration of bleed air systems to minimize dust ingestion.

• Reducing tire pressure without changing the aero plane weight, which results in the redistribution of the wheel load over a wider area thus reducing airstrip surface deflection and tire rolling resistance. This may be limited, however, by the tire design and the necessity to avoid excessive deflection of the tire under load.

• Reduction of aircraft weights if operating under reduced tire pressures.

• Aircraft modification with oversize, floatation or balloon type low pressure tires for operations on soft unpaved surfaces.

• Installation of protective systems (e.g. shields, deflectors, and filters, abrasion-resistant finishes, etc.). These protect the aircraft from hazards caused by the impingement and ingestion of stones, dust and debris.

Here is an example of a Manufacturer's Requirements provided by ATR
ATR Special Operations procedures – DRY unpaved airstrips

DRY unpaved operations approval reflects the capability of the aircraft as evaluated by its manufacturer in terms of airworthiness, but it does not constitute approval for operations in case such operational approvals required by the national Civil Aviation Authorities to the Operators and/or the local Civil Aviation Authorities.

An individual clearance for each unpaved airstrip must be obtained by the Operator from the national Civil Aviation Authority and/or the local Civil Aviation Authorities

The ATR42-500's Aircraft Flight Manual (AFM) Supplement 8.2 "Limitations" defines the following conditions for operation of an ATR42-500 on dry unpaved airstrips:

AIRSTRIP CONDITION

• DRY airstrips only, for laterite, soil or grass surface materials

• Gravel airstrips: provided they have a uniform covering of surface material that is graded smooth and kept free from ruts and standing water.

• The surface bearing material must be not less than 6 in in depth

• The airstrip surface is well compacted, with few loose stones the largest dimension of which does not exceed 50 mm (2 in)

• There are no large vegetation tufts

• The airstrip is clear of undulations and ruts

• The CBR is equal to or greater than 4.

(However, with CBR between 4 and 8 superficial damages may be caused to the airstrip)

• The stop way, if any, has similar characteristics

• The airstrip is inspected with a frequency connected to local conditions, to be sure that above conditions are satisfied.

ASSESSING AIRCRAFT DAMAGE FROM OPERATIONS ON UNTREATED UNPAVED AIRSTRIPS

The direct cost of FOD-and untreated surfaces related damage are a constant challenge to complex aircraft operators ranging from as low as tens of thousands of dollars to easily exceed one million dollars, not to mention the indirect costs associated with flight delays, aircraft changes, unscheduled maintenance, etc.

In a study released by SRI in 2018, it has been determined that indirect costs arising from a FOD or airstrip condition-related damage often equal 10-13x the direct costs. Indirect costs listed by the report include and are not limited to:

- Change of aircraft
- Close airstrip
- Corporate manslaughter/criminal liability
- Cost of corrective action
- Cost of hiring/training replacement
- Cost of rental or lease of replacement equipment
- Cost of the investigation
- Fines and citations
- Increased insurance premiums
- Increased operating costs on remaining equipment
- Insurance deductibles
- Legal fees resulting
- Liability claims in excess of insurance
- Loss of aircraft
- Loss of business and damage to reputation
- Loss of productivity of injured personnel
- Loss of spares or specialized equipment
- Lost time and overtime

• Replacement flights on other operators

• Scheduled and unscheduled maintenance

More importantly than the significant economic impact that FOD and untreated surfaces can have on an air operator's operation FOD, and airstrip condition related incident pose serious safety concerns and can result in aircraft failure, leading to the possible injuries or casualties and total write-off of the aircraft.

Besides impacting the aircraft's skin, systems, tires and propellers, untreated airstrip surfaces also may impact :

• steering,

• braking,

• takeoff and landing distances and performance.

Potholes, rutting, wash boarding, loose gravel/FOD and water pooling/ponding all contribute to challenging conditions and, in some cases, risks that pilots must assess and be aware of while operating from untreated gravel or laterite airstrips.

Gravel kits no longer prevent aircraft damage from gravel airstrips

In the past, certain complex aircraft manufacturers such as Boeing provided their aircraft with optional gravel kits to ensure added durability and protection when operating on unpaved airstrips. Gravel kits are structural modifications to an aircraft to avoid/minimize FOD damage or ingestion while operating on unpaved surfaces, allowing larger aircraft, such as the Boeing 737-200, to land on unpaved surfaces. They helped to mitigate the impacts loose gravel and dust have on aircraft. These modifications generally included deflectors, vortex dissipators, shields and reinforcements—all designed to prevent damage to the engines, underside of the fuselage and the wings. Gravel kits have been vital to protecting aircraft, keeping pilots safe and avoiding costly repairs. However this additional weight had negative impacts on limitation on carry loads as well as higher fuel consumption driving up the cost of operation.

However, in recent decades, complex aircraft manufacturers have discontinued the installation of gravel kits on new aircraft and have almost entirely phased out older aircraft that were equipped with gravel kits. This is a major and costly problem for operators , by making newer aircraft more vulnerable to FOD. Most of the new aircraft are today purely and simply unable to operate on unpaved airstrips (Boeing 737 Classic and Next Generation, Airbus A220, A320 family etc.)

UNPAVED RUNWAY TREATED WITH ENGINEERED BASE STABILIZER (EBS)

Excerpts from a Project Report and Pavement Testing Report Performed by Citation

Client: **Shell Oil**
Location: **Bolivia (very remote, with access only by air)**

Background:
Soil Solutions was contacted by Shell Oil, a Multinational Oil & Gas Company (Client) to provide a method of runway stabilization and dust control for an airstrip in Bolivia.

The existing problems included loose gravel, the loss of fine material, low visibility, dusty conditions and a slippery surface when wet. Such conditions did not allow for the use of the airstrip during and after heavy rainfall, which significantly limited the Client's plant operations, and created a safety concern.

Critical Aircraft:

Based on the past traffic that the airstrip has had and in light of its ICAO aerodrome reference code of 2-B – which intrinsically defines the types of aircraft that can operate on this airstrip – it was decided two types of aircraft should be used for reference. One has single-wheel landing gear, and the other has dual-wheel landing gear.

Aircraft	MTOW (Kg)	Landing gear configuration
Cessna 550 and 560 (jet)	7'500	Single
Beechcraft BE 1900D (turboprop)	7'700	Dual

SUBGRADE CBR

The average CBR for the subgrade soil was determined during laboratory soil testing carried out on samples extracted on site. This information is of great importance for the technical evaluation, for determining the allowable gross weight for critical aircraft and for the corresponding PCN value.

The tests yielded the following value:

Subgrade CBR = 9%

TOTAL PAVEMENT THICKNESS

Based on the available information on file from BG Bolivia and based on the soil study report, the following value was determined for the improved layer treated with engineered base stabiliser (EBS):

Wearing course thickness = 15 centimeters (150mm)

ACN FOR DUAL-WHEEL CRITICAL AIRCRAFT

Subgrade CBR	9%
Critical aircraft (dual wheel)	25,000 lbs.
Total thickness of wearing course	15 cm (150mm)
Design life	20 years
Equivalent annual departures	104

The result from the program gives a maximum permissible weight of 19,340 lbs. (8,780 kg)

Project Description:

The scope of work consisted of the cleaning of the area, contouring, and crowning of the surface to ensure for proper drainage using a grader and the removal of all loose debris, aggregate, soil and rocks from the surface followed by the application of the EBS Surface Seal.

Result:

The application of the EBS Surface Seal successfully sealed the runway surface.

Further tests conducted proved its strength and water resistance .

The upgraded airstrip surface allows for improved aircraft acceleration, as well as improved skid resistance and better pilot visibility.

This upgraded surface greatly reduced damage & maintenance of the aircraft in use.

Physical characteristics of the airstrip after treatment:

Length = 1,800 m

Width = 23 m

Average longitudinal slope = 0.34% Estimated

Transverse slopes = 1.5%

ICAO Reference Code: 2B, limited to Visual Flying Rules (VFR) operations

Airstrip surface after treatment:

Improved layer, 15 cm thick, compacted to 95% of the maximum laboratory density now coated with stabilizer which has extensive binding capability and provides a water-resistant surface that is protected from loss of fines, and any erosion, thus the surface remains as a hard long wearing surface.

Conclusion:

- An all-weather airstrip surface that is now preserved and protected from erosion and degradation (including, cracks, corrugation, and material loss),

- Another important result is being able to use the airstrip year-round, the area has a heavy rainy season which causes (untreated) airstrips not to be useable during the rainy season – which is a detriment to the plant operation.,

- The Surface Seal solution provided maintains an all-weather surface.

- In addition, this runway has now been approved as a "sealed" category of airstrip and causing Cessna Aircraft to certify the airstrip for Jet landings.

- Applying the EBS nano technology drastically reduces the cost of investment and maintenance on soil surfaces that require sealed, waterproof and dust suppressed surfaces to enhance the operation of heavy machinery, trucks, pickups, aircraft and helicopters. It also reduces the impact of dust on the surrounding environment.

- The EBS Surface Seal reduced maintenance costs and allowed the safe operation of jet engine aircraft on a gravel runway with the same results as if it were performed on a paved airstrip.

- The applied product is eco-friendly and biodegradable. It also significantly reduces the cost of decommissioning and complying with environmental regulations – emissions for maintenance activities were drastically reduced.

- The impact of this innovation was very positive, with an 85% reduction in OPEX costs related to airstrip maintenance. At the same time, it also eliminated the need to invest $US1.5m in paving to allow jet engine operations at La Vertiente airstrip and reduced emissions related to maintenance.

- La Vertiente airstrip now is the first airstrip in the country that can operate jet engine aircrafts on a ground compacted runway with no asphalt solutions, it is also the first airstrip in South America with this solution applied.

- The application of this technology can reduce costs dramatically for operations at Seismic areas for example especially when used for helipads, avoiding the premature damages of engines due to rotor wash effect. Also, in Drilling activities will help to reduce the cost of road maintenance because the product can be applied to seal the road surfaces and well spud too increasing the skid resistance for heavy equipment and waterproof surfaces.

PLANES THAT CAN OPERATE AT LA VERTIENTE AERODOME AFTER UPGRADE

Plane	Take-off weight (lbs)	Landing gear
Gulfstream Turbo Commander AC 690	10,250	Single wheel
Cessna Citation 550/560	16,500	Single wheel
Beechcraft 1900 D	17,000	Dual wheel

Conclusion:

Ensuring compliance with ICAO standards for gravel and unpaved runways is critical for maintaining safe and efficient aviation operations. The analysis presented highlights the importance of key factors such as California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), and overall pavement classification in determining the suitability of airstrip surfaces.

Unpaved airstrips present unique challenges, including material loss, rutting, and dust generation, all of which can impact aircraft performance and safety. However, through proper surface stabilization and maintenance—such as the application of Engineered Base Stabilizer (EBS)—these airstrips can be significantly improved. EBS enhances surface strength, prevents erosion, and eliminates dust, ensuring year-round operability in all weather conditions.

By implementing advanced soil stabilization technologies, operators can extend the lifespan of unpaved airstrips, reduce operational costs, and minimize environmental impact. The adoption of such sustainable solutions provides a cost-effective alternative to traditional paving methods while ensuring compliance with international aviation safety standards.

Please see the following Annexure for the ICAO Compliance Requirements

ICAO's Key Performance Requirements for Unpaved Runways

ICAO Annex 14 and ICAO Aerodrome Design Manuals outline the following guidelines:

1. **Load-Bearing Capacity:**
    - The Pavement Classification Number (PCN) must match the Aircraft Classification Number (ACN).
    - The surface must support aircraft operations without excessive deformation.

2. **Surface Quality & Smoothness:**
    - No excessive rutting, loose gravel, or depressions.
    - Loose material should be minimized to prevent FOD (Foreign Object Damage).
    - Minimal dust generation for visibility and safety.

3. **Drainage & Weather Resistance:**
    - Water should drain quickly to prevent softening.
    - Stabilized surfaces enhance water resistance and prevent erosion.

4. **Friction & Skid Resistance:**
    - The surface should provide adequate traction for braking.
    - High MPa and UCS values improve friction and prevent skidding.

5. **Dust Control:**
    - Excessive dust can obscure pilot visibility and cause engine damage.
    - Stabilized surfaces with EBS eliminate dust and prevent FOD.

Conclusion: Suitability of Materials for Unpaved Runways

Based on the ICAO recommendations, a well-constructed unpaved runway should meet the following:

Parameter	Light Aircraft	Medium Aircraft	Heavy Aircraft
CBR	6 - 10%	15 - 30%	≥ 80%
UCS (MPa)	≥ 0.8 MPa	≥ 1.5 MPa	≥ 2.5 MPa
Surface Strength (MPa)	≥ 1.0 MPa	≥ 2.0 MPa	≥ 3.5 MPa

- Materials achieving UCS of 2.5+ MPa and CBR 80%+ are highly suitable for all-weather airstrips.

- For Commercial and Military runways using very heavy aircraft (C130, IL76, etc) , EBS can provide the required stabilization based on calculated application rates based on material indicators followed by a Surface Seal – this treated surface can achieve UCS ≥ 3.5 MPa - MPa of 4.0, ensuring long-term durability.