The ACR-PCR Method to Report Airport Pavement Strength

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Outline

Outline

Bearing Strength of Airport Pavements

ICAO

International Standards
and Recommended Practices

Annex 14 to the Convention on International Civil Aviation

Aerodromes

Volume I
Aerodrome Design and Operations

Ninth Edition, July 2022

The bearing strength of a pavement shall be determined

The bearing strength of a pavement [...] shall be made available using the aircraft classification number-pavement classification number (ACN-PCN) method

(Applicable until 27 November 2024)

The bearing strength of a pavement [...] shall be made available using the aircraft classification rating-pavement classification rating (ACR-PCR) method.

(Applicable as of 28 November 2024)

made available = published in AIPs

[...] intended for aircraft of apron (ramp) mass greater than 5.700 kg

ACR and PCR Definitions

Aircraft classification rating (ACR). A number expressing the relative effect of an aircraft on a pavement for a specified standard subgrade strength

Pavement classification rating (PCR). A number expressing the bearing strength of a pavement for unrestricted operations

effect = damage
unrestricted refers to aircraft weight, not to aircraft operation

The ACR-PCR method is designed in such a way that:

- ACR of aircraft $\leq$ PCR of pavement $\Rightarrow$ the aircraft can operate on the pavement without weight or frequency restrictions
- ACR of aircraft $>$ PCR of pavement $\Rightarrow$ the aircraft may be excluded, or may be allowed to operate subject to weight and/or frequency limitations (overload operation)

Concept of the ACR-PCR Method

ICAO

Doc 9157

Aerodrome Design Manual

Part 3 — Pavements
Third Edition, 2022

The ACR-PCR method is meant only for the publication of pavement strength data in AIPs

The method is not intended for the design or evaluation of pavements

- It doesn't contemplate the use of a specific pavement design or evaluation method by States or aerodrome operators

The PCR to be reported is such that the pavement strength is sufficient for the current and future traffic

- It should be re-evaluated only if traffic changes significantly (new aircraft type or increase/decrease in traffic levels)

From ACN-PCN to ACR-PCR

The concept of the two methods is the same, both use pavement response models and damage models to calculate ACN/R-PCN/R

The main difference is that:

- empirical models are used for calculating ACN and PCN, whereas
- rational (mechanistic-empirical) models are used for calculating ACR and PCR

For ACR-PCR:

- Pavement response (stresses and strains) induced by aircraft loads are calculated using Layered Elastic Analysis (LEA)
- pavement damage is calculated using Miner's hypothesis

Mechanistic-empirical models facilitate the introduction

- Recycling technologies
- Low-energy/low-emissions materials and processes
- Enhanced durability material

Outline

Airport pavements, functions and purposes

Airport pavements must provide a smooth, skid-resistant and free-of-debris surface for aircraft operations

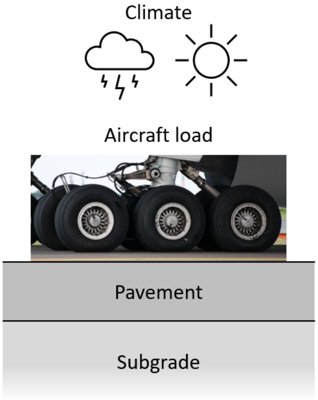
They must be designed, constructed and maintained

- to protect the subgrade and withstand the loads imposed by aircraft (bearing strength) and
- to endure adverse climatic conditions (durability)

Airport pavement structure

An airport pavement is a complex engineering structure. Its analysis and design involves the interaction of four equally important components:

- The subgrade (naturally occurring soil)
- The paving materials (surface layer, base, and subbase)
- The aircraft loads (weight, tire pressure, location and frequency)
- Climate (high/low temperatures and rainfall)



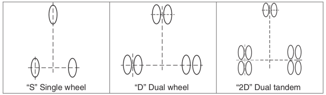
Characteristics of aircraft loads

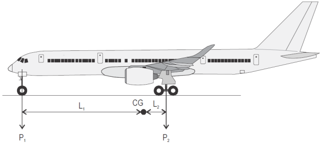
Landing gears of commercial aircraft are extremely different, they load the pavement in different locations, with different contact pressures and areas

All information is available from manufacturers and normally included in software libraries

For each aircraft type the weight distribution (position of CG) that produces the maximum load on the main landing gear (trucks located under the aircraft body) must be considered

Only takeoff operations are considered in the analysis (except for runways that are also used for taxiing)



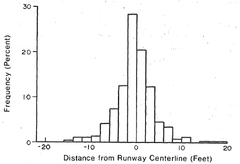


Aircraft do not travel in a perfectly straight path, and do not pass along the same path at each movement

The lateral distribution of aircraft passes is known as aircraft wander and can be described using a normal (Gaussian) distribution

- The mean is 0 (aircraft nose perfectly on center line)
- The standard deviation depends on the movement type and speed (higher for runways, lower for taxiways, almost 0 for aprons)

The effect of including lateral wander is to reduce the theoretical damage that would be caused by having all aircraft traverse a single path, i.e. $D_{\text{wander}} < D_{\text{zero wander}}$.



Equivalent Single-Wheel Load (ESWL)

A concept introduced into empirical design methods after landing gear trucks were equipped with multiple wheels to face the increase in weight og the aircraft

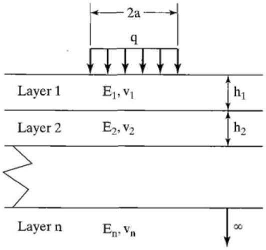
ESWL is the load value that, when applied on a single wheel, produces the same effect as a multiple-wheel truck

> effect means a displacement or a deformation or a tension, in a specific point of the pavement
>
> Example: use of ESWL in the 1956 equation of the CBR method for thickness (t) design of flexible pavements (also used for ACN calculation)

$$t = \sqrt{\frac{ESWL}{8.1CBR} - \frac{ESWL}{p \cdot \pi}}$$

A mechanistic (i.e., analytical) model is used to calculate critical stresses and strains produced by applied aircraft loads

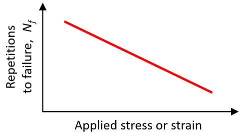
- MLE model is used for ACR-PCR calculatios (for both rigid an flexible pavements)



For damage calculation the following parameters are considered

- Horizontal stress at bottom of concrete layer, for rigid pavements
- Vertical strain at top of subgrade layer, for flexible pavements (**)
- (**) within the ACR-PCR method asphalt fatigue failure is not considered

Damage and failure due to single load applications are obtained considering Wöhler-like curves giving the number of load applications to failure as a function of the applied critical stress or strain



Failure criteria: cumulative damage

Pavement damage is produced by a collection of aircraft, each with a certain lateral wander, passing in different seasons,...

The cumulative damage factor (CDF) is calculated using the Miner's law (1945)

$$CDF = \sum_k \frac{n_k}{N_{f,k}}$$

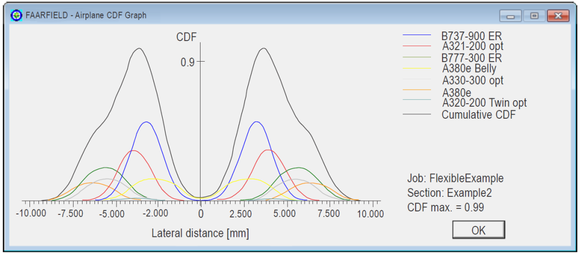
n_k number of load applications producing a certain stress/strain
$N_{f,k}$ number of load applications to failure of the same stress/strain

Failure is conventionally identified with CDF $= 1$

if CDF > 1 the pavement is underdesigned (aircraft weight or passes must be reduced)
if CDF < 1 the pavement is overdesigned (there is a strength reservoir that can be exploited)

Example CDF profiles

CDF profiles on top of subgrade, obtained for a given aircraft mix on a given (flexible) pavement



The topmost curve is the cumulative CDF profile obtained by summing the individual CDF profiles due to single aircraft in the traffic mix

- The maximum CDF is 0.99, located at a lateral offset 3.7 m from the runway centreline
- Each individual curve reflects the weight and number of passes of that aircraft, its position is related to the position of the main gear

Outline

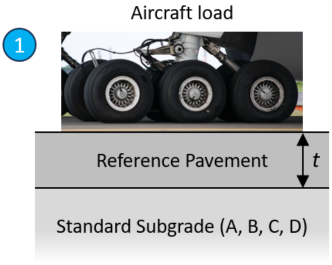
ACR definition and calculation procedure

Aircraft classification rating (ACR). A number expressing the relative effect of an aircraft on a pavement for a specified standard subgrade strength

Outline of the calculation procedure

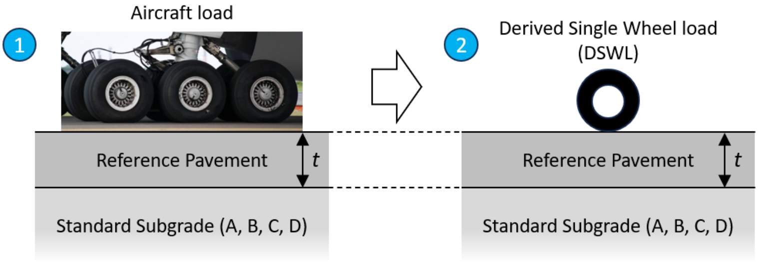
1. Design the thickness of a reference pavement, on a standard subgrade, using a mechanistic-empirical method
2. A single-wheel, with a tire pressure of 1.5 MPa, is applied on the reference pavement and the single-wheel load is adjusted to obtain the same thickness as in 1. The load is called Derived Single-Wheel Load (DSWL).
3. The ACR is two times the DSWL expressed in hundreds of kilograms

ACR calculation procedure: step 1



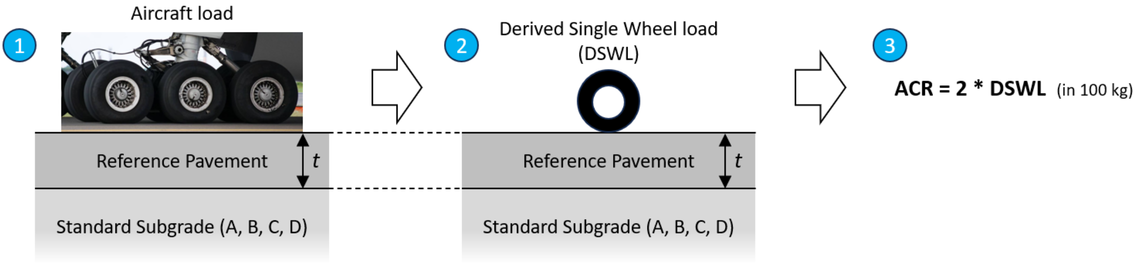
a. Select the main gear of the aircraft and the corresponding load
b. Choose the subgrade strength among one of four standard strength categories (A, B, C, D)
c. Design the thickness of a reference pavement (fixed materials, either flexible or rigid)

ACR calculation procedure: step 2



a. Apply a single-wheel, with a tire pressure of 1.5 MPa
b. Choose the same subgrade strength, one of four standard strength categories (A, B, C, D)
c. Find the single-wheel load that requires the same thickness for the same reference pavement
   $\Rightarrow$ Derived Single Wheel Load (DSWL)

ACR calculation procedure: step 3



a. Express the DSWL in hundred of kilograms
b. The ACR is two times the DSWL

$$ACR = 2 \cdot DSWL$$

May be rounded to the nearest multiple of ten (10) for publication

Who calculates and publishes the ACR?

Official ACR values are published by Aircraft manufacturers (normally the maximum ACR corresponding to the maximum ramp mass and maximum aft CG)

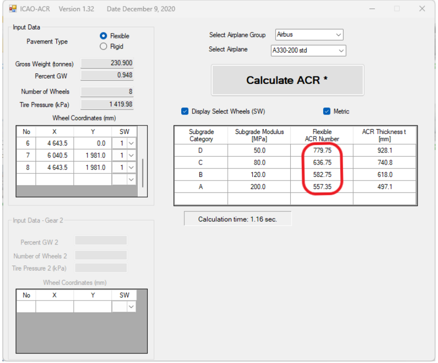
The software ICAO-ACR is published by the FAA and may be used for obtaining ACR values at lower values of operating weight

AIRBUS

A330

AIRCRAFT CHARACTERISTICS
AIRPORT AND MAINTENANCE PLANNING

AIRCRAFT TYPE	ALL UP MASS (kg)	LOAD ON ONE MAIN GEAR LEG (%)	TIRE PRESSURE (MPa)	ACR FOR RIGID PAVEMENT SUBGRADES - MPa				ACR FOR FLEXIBLE PAVEMENT SUBGRADES - MPa			
				HIGH 200	MEDIUM 120	LOW 80	ULTRA -LOW 50	HIGH 200	MEDIUM 120	LOW 80	ULTRA -LOW 50
A330-200 WV020	230 900	47.3	1.42	600	690	780	880	560	580	640	780
A330-200 WV021	230 900	47.3	1.42	600	690	780	880	560	580	640	780
A330-200 WV022	233 900	47.3	1.42	610	700	790	890	560	590	650	790
A330-200 WV023	233 900	47.3	1.42	610	700	790	890	560	590	650	790
A330-200 WV024	202 900	47.5	1.42	510	580	650	730	490	510	540	640
A330-200 WV025	220 900	47.4	1.42	570	650	730	820	530	550	600	730



PCR definition and calculation procedure

Pavement classification rating (PCR). A number expressing the bearing strength of a pavement for unrestricted operations.

Outline of the calculation procedure

0. Perform pavement evaluation (subgrade, pavement structure, traffic mix, expected life)
1. Convert the traffic mix to an equivalent aircraft traffic which will produce a CDF $= 1$
2. The ACR of the equivalent aircraft is declared as PCR

Pavement evaluation (Steps 1 and 2)

Prior to the PCR calculation, the bearing strength of a pavement shall be determined
This involves:

1. Collecting all relevant pavement data (subgrade strength, layer thicknesses, elastic moduli and Poisson's ratio of all layers) using the best available sources
2. Defining the aircraft mix (aircraft type, number of departures and aircraft) that the evaluated pavement is expected to experience over its design or estimated remaining structural life

Step 1. involves, review of existing records, visual surveys and testing using destructive and nondestructive methods

Step 2. requires the application of an empirical or rational calculation method (only rational methods based on CDF computation are allowed for calculating the PCR)

The process of pavement evaluation is the reverse of the pavement design process. If design and evaluation are carried out following different methodologies results may be different (even extremely different) because the applied failure criteria are different

Pavement evaluation (Steps 1 and 2)

Example results (FAARFIELD2 input)

Section

Job Name: PCR Examples | Life | Run

Section Name: Flexible (ADM Example 2) | ☑ Include in Summary Report | ☐ Add To Batch

Pavement Layers

Pavement Type: New Flexible

	Material	Thickness (mm)	E (MPa)	CBR
	P-401/P-403 HMA Surface	102	1 378.95	
	P-401/P-403 HMA Stabilized	127	2 757.90	
-->	P-209 Crushed Aggregate	175	467.38	
	Subgrade		200.00	19.34

Select As The Design Layer | Delete Selected Layer

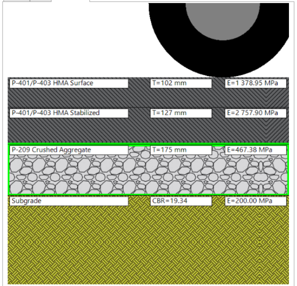
Design Life (Years): 20

The standard design life for pavement section is 20 years (1 to 50 allowed).

Results

Calculated Life (Years): 21.7 | Total thickness to the top of the subgrade: 404 mm

Status | Gear | Structure



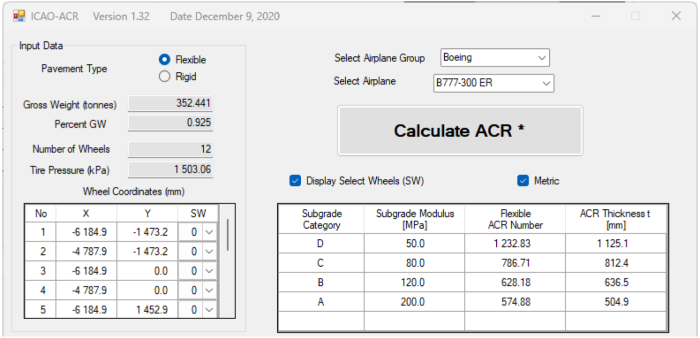
Traffic

Stored Aircraft Mix: ACR-e01 | Save Aircraft Mix to File | Clear All Aircraft from List | Remove Selected Aircraft from Section | Delete Aircraft Mix File

Airplane Name	Gross Taxi Weight (kg)	Annual Departures	Annual Growth (%)	Total Departures	CDF Contributions	CDF Max for Airplane	P/C Ratio	Tire Pressure (kPa)	Percent GW on Gear	Tire Contact Width (mm)	Tire Contact Length (mm)	Tire Contact Area (mm^2)
A330-300 std	233 900	52	0	1,040	0.02	0.13	1.86	1438.77	0.95	388	621	189 322
B777-300 ER	352 400	52	0	1,040	0.03	0.21	1.88	1502.88	0.95	380	609	182 045
A380-800 WV000	571 000	52	0	1,040	0	0.12	1.85	1527.13	0.38	372	596	174 174
A380-800 WV000 Belly	571 000	52	0	1,040	0.14	0.15	2.04	1527.13	0.57	372	596	174 174
B737-900 ER	85 400	10,950	0	219,000	0.44	0.49	1.6	1517.45	0.95	323	517	131 077
A320-200 opt	77 400	10,950	0	219,000	0.01	0.01	1.64	1422.56	0.95	318	508	126 722
A321-200 opt	93 900	1,560	0	31,200	0.28	0.32	1.6	1500.30	0.95	341	545	145 780

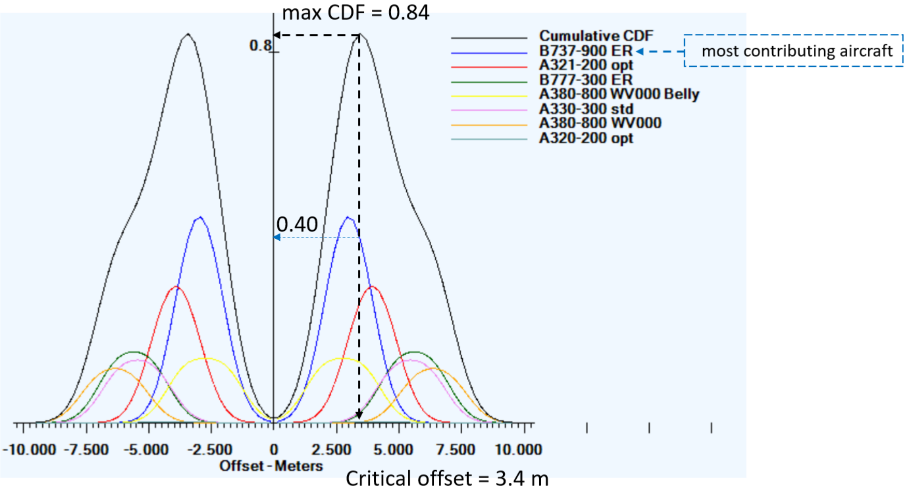
Collect ACR values (Step 3)

Record aircraft with max ACR



	A321-200	B737-900ER	B777-300ER	A320-200	A330-300	A380-800
Operating weight (t)	93.9	85.4	352.4	77.4	233.9	571
ACR	460	420	570	360	570	550

Plot CDF and find most contributing aircraft (Steps 4 and 5)



ACR of most contributing aircraft at CDF = 1 (Steps 6-9)

6. The contribution of the B737-900ER to the maximum CDF, at its initial annual departure level, is 0.40. The number of annual departures is increased until CDF = 0.84 (maximum value of the traffic mix), giving the number of equivalent annual departures of the B737-900ER

7. The gross weight of the B737-900ER is adjusted to obtain a maximum CDF = 1.0. This is the maximum allowable gross weight (MAGW) for the aircraft.

8. The ACR of the B737-900ER at its MAGW is the PCR_1 (First tentative value of the PCR)

9. Checking against the table in Step 3, it is found that the B737-900ER is not the maximum ACR aircraft. Therefore, the procedure continues to Step 10.

ACR of the next most contributing aircraft at CDF = 1 (Steps 10-12)

10. The B737-900ER is removed from the aircraft list, and all other aircraft are reintroduced. New CDF profiles are calculated (like in step 4)
11. In the reduced aircraft mix, the next most contributing aircraft is the A321-200. The maximum CDF and its location (step 5) are different because traffic has changed
12. Steps 6 to 9 are repeated until the aircraft that is the highest contributor to CDF at the critical offset is also the maximum ACR aircraft

In this example, the recursive procedure is stopped at the third potential critical aircraft. The resulting PCRi values are:

a. PCR1 425 (first critical aircraft, B737-900ER)
b. PCR2 465 (second critical aircraft of the reduced aircraft mix, A321-200)
c. PCR3 580 (third critical aircraft and maximum ACR aircraft, B777-300ER)

PCR = maximum (PCR1, PCR2, PCR3) = 585

PCR reporting: additional information

Pavement type

- R = Rigid pavement
- F = Flexible pavement

Subgrade strength

- A = High strength: $E \geq 150$ MPa (Representing value for ACR $E = 200$ MPa)
- B = Medium strength: $100 \leq E < 150$ MPa (Representing value for ACR $E = 120$ MPa)
- C = Low strength: $60 \leq E < 100$ MPa (Representing value for ACR $E = 80$ MPa)
- D = Ultra-Low strength: $E < 60$ MPa (Representing value for ACR $E = 50$ MPa)

Maximum allowable tire pressure category

- W Unlimited: no pressure limit
- X High: pressure limited to 1.75 MPa
- Y Medium: pressure limited to 1.25 MPa
- Z Low: pressure limited to 0.5 MPa

Evaluation procedure

- T = Technical
- U = Using aircraft

Published PCR

PCR 585 / F / A / W / T

Outline

Concluding remarks

Values of ACR are not related to values of ACN

Values of PCR are not related to values of PCN

Maximum values of ACR are calculated and published by manufacturers. The ICAO-ACR software may be used for mass values lower than the maximum ramp mass

ICAO provides a general procedure for calculating PCR. The following elements may be selected by States/Airport authorities

a. Design/evaluation procedure, provided it is based on the CDF calculation
b. Failure criteria, provided it's in the form of a Wöhler-like curve (only subgrade failure is considered for flexible pavements)
c. Expected life of the pavement (no limitation)

Information contained in this presentation is not exhaustive (I skipped many details), so for your calculations refer to official documents!

Airfield pavement is a precious asset that must be properly managed and maintained because aircraft operations (landing, takeoff, taxiing, parking) would not be possible without a strong safe and sustainable pavement

References

- ICAO, Annex 14 to the Convention on International Civil Aviation. Volume I Aerodrome Design and Operations. Ninth Edition, July 2022
- ICAO, Aerodrome Design Manual Part 3 - Pavements. Doc 9157 Third Edition, 2022
- FAA, Advisory Circular (AC) 150/5335-5D, Standardized Method For Reporting Airport Pavement Strength - PCR. April 2022.
- EASA Webinar on the New Method to Report Pavement Strength ACR PCR - 6 October 2022 https://www.easa.europa.eu/en/newsroom-and-events/events/new-method-report-pavement-strength-acr-pcr-webinar
- Aircraft Characteristics for Airport Planning

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