New French rational method for flexible pavement assessment and overlay design

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Presentation outline

Study framework: from semi-empirical to rational structural calculation methods

I - French rational new flexible pavement design method (recap)

II - French rational pavement assessment using HWD

III - Towards a rational method for overlay design

Conclusions and perspectives
Former semi-empirical methods for new design, structural assessment, overlay design and ACN/PCN have shown limitations

• Inspired by the US Corps of Engineers design method
• Based on the CBR method
Many limitations such as:

- No explicit consideration of asphalt material damage
- New materials not correctly considered
- No modeling of bonding conditions between layers
- No consideration of temperature and speed
- Not appropriate for new landing gear configurations
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Conclusions and perspectives
French rational new flexible pavement design method

- Released in January 2014
- Downloadable at www.stac.aviation-civile.gouv.fr

- Alizé-Airfield Pavement software
- Distributed by the ITECH company (http://www.itech-soft.com/alize)
GENERAL FEATURES – Design Principle

1- Mechanical design: Check that forecasted traffic will be handled mechanically
   • Stress-strain calculation model (ML²EA)
   • Fatigue model

2- Freeze-thaw verification: Check that environmental winter conditions will not deteriorate the pavement structure
French rational new flexible pavement design method

GENERAL FEATURES – Design Criteria

- Fatigue of HMA: \( \varepsilon_t \)
- Permanent deformations of granular materials: \( \varepsilon_z \)

Surface layer(s)
Base layer
Subbase layer
Capping layer
Subgrade
GENERAL FEATURES – Fatigue Models

For bituminous materials:
• Lab tests, Pavement Experimental Programs

For granular materials
• Field measurements and observations
• IFSTTAR APT, Nantes (FR)
French rational new flexible pavement design method

MAIN CALCULATION STEPS – Strain Maps

Elastic modulus (E) assigned to each layer (correction for speed and temperature effects)

Calculation at every node of the grid of the strains/stresses under each aircraft loading
GENERAL FEATURES – Field of Application

Distinction of 3 types of section for the design:

- Low speed
  - V = 10 Km/h

- Intermediate speed
  - V = 30 Km/h

- High speed
  - V = 100 Km/h

French rational new flexible pavement design method
French rational new flexible pavement design method

MAIN CALCULATION STEPS – Strain Maps

Example of horizontal tensile strain calculation at the bottom of bituminous layers for a 6-wheel dual tridem landing gear

Use of this signal to calculate the associated damage
MAIN CALCULATION STEPS – Damage calculation

Strain value $\varepsilon$ under loading

$\text{Fatigue Law}$

Elementary damage $\Delta D$

Which strain value? Maximum value? A combination of values?

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French rational new flexible pavement design method

MAIN CALCULATION STEPS – Damage calculation

Integration of the whole signal for damage calculation

$$\Delta D(y, z_k) = \frac{\beta}{K^\beta} \int_{-\infty}^{+\infty} \langle \varepsilon(x, y, z_k) \rangle^{\beta-1} \langle \frac{d\varepsilon}{dx} (x, y, z_k) \rangle > dx$$

Simplified expression:

$$\Delta D_{\text{tridem}} = \frac{1}{K^\beta} \left( \varepsilon_{t1}^\beta - \varepsilon_{ul12}^\beta + \varepsilon_{t2}^\beta - \varepsilon_{ul23}^\beta + \varepsilon_{t3}^\beta \right)$$
French rational new flexible pavement design method

MAIN CALCULATION STEPS – Lateral Wander

Lateral offsets from the centerline considered explicitly in the design procedure

Gaussian distribution is assumed, with a standard deviation $S_{bal}$:

<table>
<thead>
<tr>
<th>Section</th>
<th>$S_{bal}$</th>
<th>Lateral wander parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>High speed (runway)</td>
<td>0.75 m</td>
<td>1.5 m</td>
</tr>
<tr>
<td>Intermediate speed</td>
<td>0.5 m</td>
<td>1 m</td>
</tr>
<tr>
<td>(taxiways…)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low speed (aprons…)</td>
<td>0 m</td>
<td>0 m</td>
</tr>
</tbody>
</table>
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### MAIN CALCULATION STEPS – Lateral Wander

- **Traffic distribution**
  - \( \Delta y = 5 \text{ cm} \)
  - Normal centered distribution

- **Landing gear position**
  - Landing gear position for an aircraft on the centerline

- **Damage**
  - \( \Delta D(y) \)
  - Damage evolution for an aircraft on the centerline

- **Damage value for the considered trajectory**
  - \( y_j \)
  - \( (y_j)_b \)

\[ (P_j)_b = \text{area under the curve} \]

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French rational new flexible pavement design method
French rational new flexible pavement design method

MAIN CALCULATION STEPS – Lateral Wander

- Addition of the damage contribution of the aircraft passing on every trajectory (at a particular location in the pavement)
- Value weighted by the probability that the aircraft actually passes on this trajectory
- For a given depth \( z_k \) and a particular transverse position \( y_j \)

\[
\Delta D_{\text{wander}} (y_j, z_k) = \sum_{b=1}^{n_b} (P_j)_b \times \Delta D (y_j - (y_j)_b, z_k)
\]

Decrease of the damage due to lateral wander:

\[
\Delta D_{\text{wander}} \leq \Delta D
\]
French rational new flexible pavement design method

MAIN CALCULATION STEPS – Lateral Wander

Pavement design is OK when maximal damage ≤ 1
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Conclusions and perspectives
A guide for pavement testing and data analysis published in 2014

An associated software (PREDIWARE)

(STAC’s products)
Guide goal, contents, status

➢ To provide all airport technical managers an HWD pavement testing methodology

➢ For operational testing, as well as data analysis

➢ Status : the contents is to be considered as recommendations
1- Testing device requirements

<table>
<thead>
<tr>
<th></th>
<th>Resolution</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force measurement</td>
<td>0.1 kN or better</td>
<td>2 % or better</td>
</tr>
<tr>
<td>Deflection measurement</td>
<td>1 µm or better</td>
<td>2 % or better</td>
</tr>
</tbody>
</table>

Verification

STAC’s dynamic precision scales

STAC’s international round-robin
2- Knowledge of aircraft traffic

➢ Target single wheel load (SWL)
➢ Distance to area center line

3- Knowledge of the pavement structure

➢ Necessary for backcalculation
➢ GPR survey + corings required if lack of information
1- Test configuration

A- Load configuration:

➢ Max static load + hard buffers
➢ Fall height adjusted in order to reach the target load
➢ Large (45cm) 4-split load plate
B- Geophones configuration:

➢ 13 geophones for backcalculation
➢ 2 geophones for the depth to bedrock determination
C- Test sequence

\[ \Sigma = H_0 + \sum_{i=1}^{s} n_i \times H_i \]

STAC recommends:

- \( s \geq 2 \) (non-linearity study)
- \( n_i \geq 3 \ \forall \ i \) (repeatability study)

D- Test location

E- Temperature monitoring

- During the whole survey (1mes/10min)
- 3 measurement depths: top, middle and bottom of the bituminous layer
1- Preliminary studies

A- Structural homogeneous sections:

- CUSUM method on $d_{1\text{max}}$:

\[
\begin{align*}
S(P_1) &= 0 \\
S(P_2) &= S(P_1) + V_2 - \bar{V} \\
&\quad \vdots \\
S(P_{n+1}) &= S(P_n) + V_{n+1} - \bar{V} \\
&\quad \vdots
\end{align*}
\]
- Find a representative test point for homogeneous area:
  ➢ Corresponds to the point whose deflection basin is the closest to mean basin (plus 1 sigma for safety),
  ➢ This amounts to calculating:

\[
dMH_k \max = d_k \max(n) + \sigma(d_k \max(n)) \quad , \forall k = 1..m
\]

- And minimizing

\[
e_d = \sqrt{\frac{\sum_{k=1}^{m} (d_k \max - dMH_k \max)^2}{m}}
\]
2- Backcalculation

➢ According to STAC’s dynamical FE method:

➢ Minimization of:

\[ f_I(\vec{E}) = \sum_{k=1}^{m} q_k \int_{t = t_{\text{min}}}^{t_{\text{max}}} \left( w_k(\vec{E}, H, \vec{v}, r_k, p, a, t) - d_k(t) \right)^2 dt \]

➢ FE mesh:

➢ Backcalculation results:
3- Temperature/frequency corrections

➢ Backcalculation provides Young’s moduli at temperature and pseudo-frequency of the HWD test

➢ Young’s moduli of bituminous material are sensitive to frequency, and highly sensitive to test temperature

➢ It is necessary to apply corrections to backcalculated values before any forward analysis, to obtained moduli at a reference temperature (15°C in French design, for metropolitan airports)
➢ Test temperature is defined as the mean temperature in the bituminous layer

➢ Temperature is corrected using material lab testing results, or STAC’s correction law

➢ Frequency is corrected using lab testing results, or is neglected.
4- Forward calculation

➢ Single Wheel Load bearing capacity (SWL):
Determination of the F load, applied on a Ø45 HWD plate imparting a S=1 maximal cumulated damage for $10^4$ loads (no lateral wandering).

➢ PCN$_{HWD}$: $PCN_{HWD} = 2 \times SWL$

➢ Residual life:
Determination of the time corresponding to a maximal cumulated damage of «1», when considering all critical layers, according to the foreseen traffic - lateral wandering taken into account.
Calculation is performed in accordance with the French rational method.

➢ Overlay design:
Needed if $PCN_{HWD}$, or residual life are not in accordance with expectations.
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Conclusions and perspectives
Rational method for overlay design

- Development on progress

- Method philosophy elaborated + validated by an expert group comprised of pavement specialists and airport pavement managers

- General idea: to rely on field measurements (distress mapping, corings and GPR, HWD survey), rather than on theoretical damage calculations from pavement history and passed traffic

- Parameters to be fitted using in-situ full scale tests and/or airfield APT data

- Decision tree
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Conclusions and perspectives
Conclusions and next work

Flexible pavement
➢ Release of new design / structural assessment / overlay design
➢ Consistent together and with the ACR/PCR method philosophy

Next work
➢ Transpose this work to rigid pavement
➢ Work in progress for structural assessment and new design
Thank you for attention…