Impact of site location and groundwater table depth on the thickness of flexible airfield pavements

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Agenda

Intro
Objective
Analysis
Results
Summary and Conclusions
Recommendations
part I: introduction
Environmental effects on pavement design and performance is a fundamental component of any Mechanistic-Empirical Pavement Design procedure.
However, current airfield design procedures do not consider the effects of groundwater table depth and the effect due to environmental conditions.
There is a significant need to incorporate the influence of environmental site factors and the groundwater table depth upon flexible airfield pavement design and performance.
A methodology and computer code has been developed at Arizona State University that allows for this analysis, including special considerations for unsaturated regions.
part II: objective
Provide a quantitative assessment of the potential benefits and savings in pavement design thickness that occur due to the inclusion of specific environmental site properties.

Environmental site properties analyzed included moisture, temperature and groundwater table depth.
The study focuses upon the prediction of pavement thickness to guard against excessive shear deformations or rutting for asphalt pavements.

Analysis is provided for a series of aircraft types, subgrade support values, different geographic locations across the US, and a range of GWT depths.
part III: the analysis
5 different climatic conditions
6 groundwater table depths
3 subgrade soils

Experimental Matrix

2 levels of design traffic
3 aircraft types
This study used the Limiting Subgrade Strain criteria developed for the newly revised USACE-\(\beta\) approach.
The Limiting Subgrade Strain criteria is a performance criteria applicable to design for excessive shear deformations (rutting) of the pavement.
The USACE limiting strain criteria is expressed as follows:

\[
\log(\varepsilon_{y_{sg}}) = \frac{-2.1582 - 1.3723 \log(N_f)}{1 + 0.4115 \log(N_f)}
\]
Input Needed
## Material Properties and Structure

<table>
<thead>
<tr>
<th>Layer Number</th>
<th>Material Type</th>
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<th>3</th>
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<td>Base</td>
<td>Subbase</td>
<td>Subgrade</td>
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<td>( w_{\text{opt}} ) %</td>
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<td>( \gamma_{d \text{ max}} ) (pcf)</td>
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<td>130</td>
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ZAPMEDACA
implementation
modules
### Load Configuration

#### Airbus A-380

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<th>Value</th>
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<td>Distance Between Loading Points, $S_d$ (in)</td>
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<td>Load per Tire (lb)</td>
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<td>Tire Pressure (psi)</td>
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<tr>
<td>Pressure Distribution</td>
<td>Uniform</td>
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<td>Tire Imprint Shape</td>
<td>Elliptical</td>
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<tr>
<td>Number of the Main Gear for Each Side</td>
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<td>Pavement Width Analyzed, (ft)</td>
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<td>Number of Longitudinal Segments (dy) in Tire Imprint</td>
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<tr>
<td>Number of Transversal Segments (dx) in Tire Imprint</td>
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<tr>
<td>Number of Radial Segments (dr) in Tire Imprint</td>
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<tr>
<td>Size of Angular Segments (dθ) in Tire Imprint</td>
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<td>Distance to Mean Location of Load for main Gear1, $x_{j1}$ (ft)</td>
<td>20.40</td>
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<td>Distance to Mean Location of Load for main Gear2, $x_{j2}$ (ft)</td>
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<td>Horizontal Tire Spacing, $S_{d1}$, $S_{d2}$ (in)</td>
<td>53.10</td>
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<tr>
<td>Vertical Tire Spacing, $S_{t1}$, $S_{t2}$ (in)</td>
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</table>

#### Loading Points Cartesian Coordinates (in)

<p>| | | | | | | | | | |</p>
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<td></td>
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<td>127.35</td>
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## Pavement Structure and Material Properties

### INPUT:

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<thead>
<tr>
<th>Number of Layers</th>
<th>Ground Water Table Depth, (ft)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Layer Number</th>
<th>Material Type</th>
<th>Thickness (in)</th>
<th>Poison Ratio, ( u )</th>
<th>( E^* ) or ( E ) at Optimum Conditions, (psi)</th>
<th>CBR (%)</th>
<th>R value</th>
<th>AASHTO Layer Coefficient, ( a_i )</th>
<th>Soil Classification (AASHTO or SUCS)</th>
<th>Percentage Passing Sieve #200, ( P_{200} )</th>
<th>Plasticity Index, ( P_I )</th>
<th>Specific Gravity of Solids, ( G_s )</th>
<th>Optimum Moisture Content, ( w_{opt} ) %</th>
<th>Maximum Dry Density, ( Y_{d,max} ) (pcf)</th>
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<tbody>
<tr>
<td>1</td>
<td>Asphalt</td>
<td>8.00</td>
<td>0.35</td>
<td>300,000</td>
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<td>A-1-b</td>
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<td>14</td>
<td>2.65</td>
<td>8</td>
<td>130</td>
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<tr>
<td>2</td>
<td>Gran. Base</td>
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### CORRECTION FACTOR FOR TRANSFORMED SYSTEM

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<td></td>
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<td>0.80</td>
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Traffic Input

Passes of Vehicle at Base Year, Pjo
Design Life (yr)
Traffic Growth Rate (%)
Passes of Vehicle at End of Design Life, Pjt
Gear Wander Standard Deviation, f_jx (ft)

<table>
<thead>
<tr>
<th>Pjo</th>
<th>4000</th>
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<tbody>
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<td>Design Life</td>
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<tr>
<td>Traffic Growth Rate (%)</td>
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<tr>
<td>Passes of Vehicle at End of Design Life, Pjt</td>
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<tr>
<td>Gear Wander Standard Deviation, f_jx (ft)</td>
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## Environmental Effects

### City
- **Phoenix-AZ**
  - Longitude in decimal: -112.07
  - Latitude in decimal: 33.45
  - TMI: -54.95

### Table

<table>
<thead>
<tr>
<th>Layer</th>
<th>Suction, $\psi$ (psi)</th>
<th>SWCC Constants</th>
<th>Degree of Saturation, S%</th>
<th>S% at Optimum</th>
<th>Environmental Factor, $F_U$</th>
<th>Resilient Modulus, $M_R$ (psi)</th>
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<tbody>
<tr>
<td>Above GWT: Asphalt</td>
<td>9</td>
<td>5.0 3.28 1.28 500</td>
<td>55.7</td>
<td>93.6</td>
<td>1.512</td>
<td>60,462</td>
</tr>
<tr>
<td>Above GWT: Gran. Base</td>
<td>9</td>
<td>5.0 3.28 1.28 500</td>
<td>55.7</td>
<td>93.6</td>
<td>1.512</td>
<td>60,462</td>
</tr>
<tr>
<td>Below GWT: Gran. Base</td>
<td>0</td>
<td>0 0 0 0</td>
<td>100.0</td>
<td>93.6</td>
<td>0.937</td>
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<td>Below GWT: Gran. Sub-base</td>
<td>0</td>
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<td>100.0</td>
<td>77.4</td>
<td>0.539</td>
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<tr>
<td>Below GWT: Subgrade</td>
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<td>83.8</td>
<td>0.402</td>
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### Stress Analysis

#### Computation of Depths (in)

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<th>Depth 4</th>
<th>Depth 5</th>
<th>Depth 6</th>
<th>Depth 7</th>
<th>Depth 8</th>
<th>Depth 9</th>
<th>Depth 10</th>
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<tbody>
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<td>Z</td>
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#### Computation Points (in)

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<th>X₁₂</th>
<th>X₁₃</th>
<th>X₁₄</th>
<th>X₁₅</th>
<th>X₁₆</th>
<th>X₁₇</th>
<th>X₁₈</th>
<th>X₁₉</th>
<th>X₂₀</th>
<th>X₂₁</th>
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<td>127.35</td>
<td>172.8</td>
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<td>244.8</td>
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<td>Y₁₂</td>
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</tr>
</tbody>
</table>

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The image shows a grid with points of interest marked with red crosses, alongside the location of tires indicated with blue circles.
Stress Analysis

Airbus A-380 Shell Oil Criteria (Airfields)

Half of Strain Profile under the Main Gear

Chart Area

Transverse Profile (inch)

Strain Profile under Main Gear

Aircraft Center Line
Rutting Design Criteria
Rutting Design Criteria
<table>
<thead>
<tr>
<th>Year</th>
<th>Annual Traffic (Pass)</th>
<th>Annual Max Damage (%)</th>
<th>Cumulative Traffic (Pass)</th>
<th>Cumulative Max Damage (%)</th>
<th>Interval of the Max Damage, Xj- max (ft)</th>
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<td>4040</td>
<td>31.17</td>
<td>4040</td>
<td>31.17</td>
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<td>35.80</td>
<td>34674</td>
<td>267.50</td>
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<td>4733</td>
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<td>45.40</td>
<td>98158</td>
<td>757.26</td>
<td>± 0.5</td>
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</table>
part IV: the results
**Resulting subgrade modulus after considering the environmental effects for 5 cities**

<table>
<thead>
<tr>
<th>$M_r$ (opt)</th>
<th>$M_r$ (Sat)</th>
<th>$M_r$ for Unsaturated Soil Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>Athens</td>
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<td>$M_r$</td>
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<tr>
<td>20048</td>
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</table>
Resulting *subgrade modulus* after considering the environmental effects for 5 cities
Cost savings are proportional to savings of subbase thickness.
<table>
<thead>
<tr>
<th>Number of Passes</th>
<th>MR of Subgrade (psi)</th>
<th>GWT (ft)</th>
<th>Boeing B737-600</th>
<th>AIRBUS INDUSTRIE A300-C4</th>
<th>BOEING B747-400</th>
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Required subbase thickness (in) for Boeing B737-600
Required subbase thickness (in) for **Airbus A300-C4**
Required subbase thickness (in) for Boeing B747-400
N = 100,000
Required subbase thickness (in) for Boeing B747-400
N = 1’000,000
part V: summary and conclusions
ZAPMEDACA software/program is a powerful analytical tool that incorporates environmental effects in airfield design.
This has not been accomplished by any other airfield pavement design procedure used in the world!!
Savings of subbase material up to 2.5 feet for lighter B-737 aircraft to as much as 3 to 8 feet for heavier B-747 aircraft may occur when unsaturated soil mechanics / environmental conditions are incorporated in the pavement design process.
Savings are obvious when design thicknesses are compared to those obtained with the classical assumption used in most pavement design methods that rely upon fully saturated evaluation of all unbound material layers.
Results generated from this study provide **quantitative evidence** of the significant savings that may be accrued in the design, construction and rehabilitation of airfield pavements by using unsaturated soil mechanics principles in the design methodologies.
part VI: recommendations
Several major additions need to be made to enhance ZAPMEDACA to consider a wider range of computational improvements, additional distress types and real time environmental model changes in unbound layers for flexible airfield pavement systems.
Controlled full-scale field tests to validate the results of ZAPMEDACA analysis are necessary and highly recommended
Major US and International airfield pavement design agencies responsible for airfield operation should carefully re-evaluate the current state of the practice and move to incorporate more precise and rational theories and methodologies.
The authors would like to acknowledge the general guidance, valuable input and recommendations given by Professor Matthew Witczak
part VII: acknowledgments
part VIII: thanks!