Some modelling results on flexible pavements obtained with the help of ViscoRoute Software

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Outlines - Questions

- General considerations
  - European and French worries in relation to loading topics
  - French design method
  - Some needs to improve the French method
  - Actual (2006-2009) LCPC research programs

- For this workshop
  - ViscoRoute contribution
  - Informations we are interesting to get

- Conclusions
European norm: 40T max; 11.5T max/axle

European norm and possible modifications

- 44T max (may be more?) instead of 40T for France
- 11.5T max/axle instead of 13T max for France

-> multi axles problems
Twin wheels or wide base tire?

(AI Qadi et al., 2004)

Figure 3.1. Evolution of Wide Base Tires

AIRBUS experimentation
(LCPC/STBA)

Typical signals recorded in the pavement under the vehicle
Aeronautic applications
(PEP souple 1999) (Lohf, 2005)

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Based on Burmister modeling (1947)
- Multi-layered modeling
- Circular uniform loading
- 2D axisymmetrical modeling, superimpose loading assumptions
- Elastic material behavior
- Time and temperature / frequencies assumptions

French design method for asphalt pavements (SETRA-LCPC, 1994)

\[ \varepsilon_{t,\text{adm}} \leq \varepsilon_6 \times \left( \frac{NE}{10^6} \right)^b \times k_c \times k_r \times k_s \times k_d \]

NE: number of equivalent ref. axles (France -> twin wheels 130kN) (norme NF 98-082)
b: fatigue slope
ki: factors (uncertainties: traffic risk, structure type, thickness layers, ...)

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International Workshop on Use of Wide Base Tires
FHWA - MClean - October 22-23 2007
The French design method OK

Relative good predictions for design problems

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For diagnostic problems

-> Some pavement needs

1. Crack discontinuities modeling for cement concrete structure
2. Viscoelastic behavior of asphalt materials for flexible pavement
3. No-linearity behavior of sub-base and subgrade layers
4. Better modeling of multi-loadings and tire-pavement contact
5. ...

LCPC research programs (2006-2009):
- Up to date French Design method (P. Hornych)
- Fundamental Modelings (A. Chabot, http://or.lcpc.fr/fondephy)

The needs

For engineers A fast tool needs to be used
(with semi-analytical solutions)

TODAY:
Crack discontinuities modeling for cement concrete structure
- Viscoelastic behavior of asphalt materials for flexible pavements
- No-linearity behavior of sub-base layers
- Better modeling of multi-loadings and tire-pavement contact
Software ViscoRoute
(Duhamel et al., BLPC2005)
(Chabot et al., ICAP2006)

A. Chabot, P. Tamagny, *D. Duhamel
D. Poché, A. Lohf, T. Nguyen, Senti A.

Division Matériaux et Structures de Chaussées
LCPC - Centre de Nantes - France
* Laboratoire Analyse des matériaux et Identification
ENPC - Marne la Vallée - France
1. Huet-Sayegh modeling (1965)

$$E^*(\omega, \theta) = \frac{c_0}{1 + i\delta(\omega \tau)} + \frac{c_0}{(i\omega \tau)^k} \exp(\beta(1 + i\omega \tau)^2)$$

$$\tau(\theta) = \exp(A_0 + \theta + \theta^2)$$

(Huet 1963), (Huet, Mechanics and Materials, 31, 1999), (Sayegh, 1965)

Viscoanalyse Software (Chailleux, 2006)

http://www.lcpc.fr/fr/produits/viscoanalyse/index.dml
1. And/Or ... ViscoMatData

- Project 2007:
  Data base for complexe modulus behavior of bitumen, asphalt and other viscoelastic materials coefficient (Huet, Huet-Sayegh, prony series,... s) and fatigue- damage parameters
- Internet and intranet base
- To follow...

2. Structural mechanical modelling

![Diagram showing structural mechanical modelling](image-url)

- Moving load $F(X,Y,Z)$
- Soil
- Layers $i$, $E^i$, $p^i$, $\nu^i$
- Layer $n$
Method (Nguyen, 2002)

The Time dependance problem can be solve with:

- **Change of variables**
  \[(x, y, z) \rightarrow (X - Vt, Y, Z)\]

- **Use of double Fast Fourier Transform**
  \[(X - Vt, Y, Z) \rightarrow (p, q, Z)\]

**Analytical Elastic problem**

\[
A_i \frac{\partial^2 \hat{u}(p, q, Z)}{\partial Z^2} + jB_i \frac{\partial \hat{u}(p, q, Z)}{\partial Z} - C_i \hat{u}(p, q, Z) = 0
\]

Viscoroute kernel

(Duhamel et al., BLPC2005)

- **Solutions in Fourier\((p,q,Z)\) frame: 6 complex constants**

  \[
  \hat{u}_i(p, q, Z) = p \beta_{1i}^- e^{-\kappa p Z} + \kappa_i \beta_{3i}^- e^{-\kappa_i Z} + p \beta_{1i}^+ e^{\kappa p Z} - \kappa_i \beta_{3i}^+ e^{\kappa_i Z}
  \]

  ....

- **Solutions in real \((X,Y,Z)\) frame:**

  \[
  f(X,Y,Z) = \frac{1}{4\pi^2} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \hat{f}(p,q,Z) e^{i(pX+qY)} dp dq
  \]

**Use of double Inverse Fourier transform method**
Viscoroute-v1:
(Duhamel D., Chabot A., Tamagny P., Harfouche L., BLPC 2005)

Comparison Applications
Validations
(Duhamel et al., BLPC 2005)
(Chabot et al., ICAP 2006)

1. Calculus: ALIZE, CVCR (3D FEM)
   (Heck et al., 1999)

2. Experimental datas (fatigue tests)

Manège de fatigue
of LCPC-Centre de Nantes

Viscoroute Post-treatment development
(Senti, 2007)

More informations required

More informations required
Use of Shannon theorem
(Scilab post-traitement - Senti, 2007)

- If \( f(t) \) finite,
- If \( f(t) \) is zero on its edge then

\[
f(t) = \sum_{n=-\infty}^{\infty} f(na) \frac{\sin\pi(t-na)}{a} \frac{\pi}{a(t-na)}
\]

The signal is perfectly rebuilt

Comparison with Veroad results
(Nilsson et al., RMPD2002) (Senti, 2007)

Loading area
- Veroad: \( R=140\text{mm}=0.14\text{ m} \) - \( S=\pi R^2=0.0616\text{ m}^2 \)
- Viscoroute-v1: \( 2a=2b=0.24814\text{ m} \)
Maximum Structure 2 strains (z=0.2m) depending on speed and temperature (Senti, 2007)

Maximum Structure 1 strains (z=0.1m) depending on speed and temperature (Senti, 2007)

Top – down cracking
(Tamagny et al., CP2004)

3D viscoelastic calculus with CVCR- César FEM code
(Heck et al, 1998)
Study of viscoelastic effects on the top of the pavement (Senti, 2007)

24 cm GNT 
E=400 Mpa

Sol élastique
E=50MPa
(épaisseur infinie)

13 T
dual tire = 6.5 T
single = 3.25 T = 0.662 MPa
single = 32500 N

\[
\varepsilon = 0.001
\]

\[
E = 400 \text{ MPa}, \nu = 0.35
\]

\[
E = 50 \text{ MPa}, \nu = 0.35
\]

\[
T = 15 \degree C
\]

\[
A = 1.377
\]

\[
A = 0.35698
\]

\[
A = 0.001743
\]

\[
\text{dual tire) } = 6.5 \text{ T}
\]

\[
\text{single) } = 3.25 \text{ T) } = 0.662 \text{ MPa}
\]

\[
\text{single) } = 32500 \text{ N}
\]
Study of viscoelastic effects on the top of the pavement (Senti, 2007)

\begin{center}
\begin{tikzpicture}
\begin{axis}[
    xlabel={X(m)},
    ylabel={syz (x, 0.2, 0.001) (Pa)},
    xmin=-2, xmax=2,
    ymin=-10000, ymax=0,
    xtick={-2, -1.5, -1, -0.5, 0, 0.5, 1, 1.5, 2},
    ytick={-10000, -8000, -6000, -4000, -2000, 0},
    grid=both,
    legend entries={\text{agg 30° viscoélastique 0.001}, \text{agg 15° viscoélastique 0.001}, \text{agg 15° élastique 0.001}},
    legend style={at={(0.5,0)},anchor=north},
]
\addplot[red, line width=1.0pt, mark size=1.5pt] coordinates {
(-2, -10000)
(-1.5, -9000)
(-1, -7000)
(-0.5, -5000)
(0, -3000)
(0.5, -1000)
(1, 0)
(1.5, 0)
(2, 0)
};
\addplot[blue, line width=1.0pt, mark size=1.5pt] coordinates {
(-2, -9000)
(-1.5, -8000)
(-1, -6000)
(-0.5, -4000)
(0, -2000)
(0.5, 0)
(1, 0)
(1.5, 0)
(2, 0)
};
\addplot[black, line width=1.0pt, mark size=1.5pt] coordinates {
(-2, -8000)
(-1.5, -7000)
(-1, -5000)
(-0.5, -3000)
(0, -1000)
(0.5, 0)
(1, 0)
(1.5, 0)
(2, 0)
};
\end{axis}
\end{tikzpicture}
\end{center}
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Prospects - Interest 1

- Introduction of non-uniform loading coming from:
  - The literature (De Beers et al., 1997, ICAP2006).
  - Experimental data (LCPC research program 2006-2009)

  (Hamlat et al., 2006)

- That group?
Prospects - Interest 2

- Comparison with other results coming from 3D-Move (Siddharthan et al., 1998), 3D Abaqus FEM (Al Qadi et al., 2004)

![Figure 3.1. Evolution of Wide Base Tires](Al Qadi et al., 2004)

Interest 3: Data analyse of old Load configurations ALT
LCPC manege tests

- 1997 - Michelin test data on dual-tire comparison with wide base-tire
- April 1999 - COST 334
- Juillet-septembre 1999 – rutting test TVM (Trans Val de Marne) -Michelin tires- tramway - ringB -

-> wide base tire equivalent to dual tire?

Examples of tests

- Fatigue experiment on asphalt pavement
- Rutting experiment on asphalt pavement (ultra canalized urban traffic)
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Conclusions

Free downloading on www.lcpc.fr/fr/produits/

- ViscoAnalyse - V1 Software (Chailleux et al., RMPD 2006)
- ViscoRoute - V1 software (Duhamel et al., BLPC2005)
  - 3D modeling
  - 1 rectangular uniform loading - (vertical and shear forces)
  - Bonding layers
  - Elastic and huet-Sayegh viscoelastic behavior
  - Fast, Applications (design: $F \leftrightarrow V$, $T^\circ C$, exp., consumption calculus, ...)
  - available at the end of 2007

-> coming soon ViscoMatdata
Prospects

- Validations for viscoroute-V2 (O. Chupin)
  - Elliptical and rectangular loading + multi loading effects
  - Non uniforme loading introduction
- Viscoroute-V3 – 2008 (O. Chupin)
  - Debonding between layers
- non linearity of the soil?...

- 3D FEM Cesar-LCPC -> ORNI
- LCPC research program (http://or.lcpc.fr/fondephy)

Thanks for your attention

Objective: Engineer tools