THE EFFECT OF GEOMETRICAL DISPOSITION OF IMPERMEABLE MEMBRANES ON THE SUBGRADE SERVICE LIFE OF RAIL TRACK EMBANKMENTS

M. O. Ciantia  J. Pérez-Romero  J. Vaunat  M. Arroyo
eco-Friendly And Sustainable slab TRACK for high-speed lines
OUTLINE

INTRODUCTION
   *Overview of the problem and objectives

AASHTO INDICATIONS
   American Association of State Highway and Transportation Officials
   * Long term, environmental induced traffic irreversible deformations

2D HYDRO-THERMAL ANALYSES
   *Geometrical positioning of impermeable membranes
   *Embankment dimensions
   *Water table depth
   *Climate

LONG TERM EMBANKMENT DEFORMATION
   Fatigue based environmental induced irreversible deformations

CONCLUSIONS
High speed train tracks

**Ballastless vs Ballasted track**

- Ballastless track (example)
  - Continuous slab of concrete (like a highway structure) with the rails supported directly on its upper surface (using a resilient pad)
  - Advantages of Ballastless tracks (Michas, 2012):
    - Less maintenance and longer life time
    - High stability and efficient load redistribution
    - Higher precision during construction
    - Good design for high speed trains > 300 km/h
    - Reduction of vegetation maintenance costs
Lifetime embankment deformation

$\text{S}_U = \text{Bed settlement}$

$\text{S}_E = \text{Embankment settlement}$

$\text{S}_V = \text{Traffic load settlement}$

TOTAL settlement = $\text{S}_U + \text{S}_E + \text{S}_V$
Embankment deformation

Embankment settlement
Bed settlement
TOTAL settlement

Traffic load settlement

Embankments substructure superstructure

construction time

service time

t₀

t_service

time → ∞
OBJECTIVE:
LONG TERM EMBANKMENT SETTLEMENT

1. Embankment settlement due to self weight + environmental loads

2. Embankment settlement due to traffic loads + environmental loads

HOW??
Uncoupled TH - M analyses based on the AASHTO indications
\[ \varepsilon_v(N) = \varepsilon_v^0 \beta_1 \left( \frac{\varepsilon_0}{\varepsilon_r} \right) e^{-\left( \frac{\rho}{N} \right)^\beta} \]

\[ \log \beta = -0.61119 - 0.017638 W_c \]

\[ \log \left( \frac{\varepsilon_0}{\varepsilon_r} \right) = 0.5 \left[ e^{(\rho)^\beta} a_1 + e^{(\rho/10^9)^\beta} a_9 \right] \]

\[ \rho = 10^9 \left( \frac{C_0}{\left( 1 - (10^9)^\beta \right)} \right)^{\frac{1}{\beta}} \quad C_0 = \ln \left( \frac{a_1}{a_9} \right) \]
AASHTO: Fatigue based calculation -2

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**SEPARATE MECHANICAL ANALYSIS**

**EMPIRICAL**

\[ W_c = 51.712 \left[ \left( \frac{E_r}{2555} \right)^{\frac{1}{0.64}} \right]^{-0.3586*GWT^{0.1192}} \]

\[ \log \frac{M_R}{M_{R_{opt}}} = a + \frac{b - a}{1 + EXP \left( \frac{\ln \frac{b}{a} + k_m \cdot (S - S_{opt})}{a} \right)} \]

**NUMERICAL**

**HYDRO-THERMAL NUMERICAL ANALYSES**

CODE_BRIGHT

environmental boundary conditions
\[ \varepsilon_v (N) = \varepsilon_0^0 \beta_1 \left( \frac{\varepsilon_0}{\varepsilon_r} \right) e^{-\left( \frac{\rho}{N} \right)^\beta} \]

\[ \log \beta = -0.61119 - 0.017638 W_c \]

\[ \log \left( \frac{\varepsilon_0}{\varepsilon_r} \right) = 0.5 \left[ e^{\rho^\beta} a_1 + e^{(\rho/10^9)^\beta} a_9 \right] \]

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\[ C_0 = \ln \left( \frac{a_1}{a_9} \right) \]

\[ W_c = 51.712 \left( \frac{E_r}{2555} \right)^{0.64} \]

\[ \log \frac{M_R}{M_{R_{opt}}} = a + \frac{b - a}{\ln \exp \left( \frac{\ln -b}{a} \right)} \]

Moço Ferreira T. & Fonseca Teixeira (2012)

**Numerical**

**Empirical**

\[ W_c = 0.3586 \cdot GWT^{0.192} \]
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AASHTO INDICATIONS
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LONG TERM DEFORMATION
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T-H MODEL: Geometrical specifications

Diagram showing the geometrical specifications of a hydro-thermal model with various layers and markers. The diagram includes labeled sections and markers for detailed analysis.
### M MODEL: Calculating $\varepsilon_v$

#### Introduction

- AASHTO Indications
- 2D Hydro-Thermal Analyses
- Long Term Deformation
- Conclusions

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#### Calculating $\varepsilon_v$

**Self-weight**

$$\varepsilon_v$$

**Traffic**

$$\varepsilon_v$$
T-H MODEL: CODE_BRIGHT

ATMOSPHERE:

At soil surface:

Heat exchange:
- Solar radiation (+)
- Radiation re-emitted by the atmosphere (+)
- Radiation re-emitted by the soil (-)
- Heat convected by evapotranspiration (in particular latent heat) (-)
- Heat convected by liquid water (+/-)
- Heat convected by air

Water exchange:
- Precipitation (+)
- Runoff (-)
- Evapotranspiration (-)

Air exchange:
- Flow due to change in atmospheric pressure
- Strongly enhanced by aerodynamics effects
SOIL:

- Sensible Heat
- Latent Heat
- Radiation
- Precipitation
- Evaporation
- Runoff
- Gas Flux

Mass balance of heat (including conductive, diffusive and advective fluxes)

Mass balance of water (including liquid water and vapour)

Mass balance of air (including dry air and dissolved air)

Stress equilibrium
**INTRODUCTION**

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**LONG TERM DEFORMATION**

**CONCLUSIONS**

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**T-H MODEL: Materials**

**Grain Size Distribution**

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**Track Bed Layer**

**Subgrade**

**Embankment (Nucleous)**

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<th>Track bed layer</th>
<th>Subgrade</th>
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<th>Nucleus B</th>
<th>Nucleus A</th>
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<td>MPa</td>
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<td>$c'$</td>
<td>kPa</td>
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<td>NP</td>
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<td>37.6</td>
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<td>50</td>
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T-H MODEL: Boundary Conditions #1

WEATHER

S. Sebastián

Antequera
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WEATHER

Antequera

S. Sebastián
T-H MODEL: Boundary Conditions #2
IMPERMEABLE GEOMEMBRANES
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Type of NUCLEOUS #1

NU_A
10 years 2 years
2E-10 m/s

NU_B
10 years 5 years
2E-9 m/s

NU_C
10 years 5 years
2E-8 m/s

2 years

5 years

10 years
Type of NUCLEOUS #2

PERMEABILITY

2E-10 m/s

2E-9 m/s

2E-8 m/s
EMBANKMENT DIMENSIONS

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T-H MODEL: Typical Results
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T-H + M MODEL: Long term embankment irreversible deformations

\[ \delta_a (N) = \beta_1 \left( \frac{\varepsilon_0}{\varepsilon_r} \right) \left( \frac{\rho}{N} \right)^\beta \left( \varepsilon_v h \right) \]

\[ \log \beta = -0.61119 - 0.017638 W_c \]
T-H + M MODEL: Long term geomembrane positioning #1
T-H + M MODEL: Long term geomembrane positioning #2
T-H + M MODEL: Long term geomembrane positioning #3
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T-H + M MODEL: Long term geomembrane positioning #4
10 year self weight and traffic load env-induced settlement
NEW WAY OF PREDICTING THE ATMOSPHERIC INDUCED LONG TERM DEFORMATION OF EMBANKMENTS:

AASHTO INDICATIONS (FATIGUE CALCULATION) + TH FEM ANALYSES

PARAMETRIC STUDY:

1. GEOMETRICAL DISPOSITION OF IMPERMEABLE MEMBRANES
2. PHREATIC LEVEL
3. SIZE OF THE EMBANKMENT
4. CLIMATE

FURTHER RESEARCH

1. MEMBRANES AT THE BASE
2. FULLY COUPLED THM FEM ANALYSES
Thanks for the attention
QUESTIONS?