2D Multilayer Analysis of Electrified Roads with Charging Box Discontinuities

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Context and background

In order to attain the reduction of CO₂ emissions under the objectives of European Energy Agency (EEA 2016), one of the solutions proposed being is the electrified Roads (eRoad) → Challenge for 2030!

- Catenary
- Conduction
- Solar
- Induction

http://www.siemens.com/presspict/SIEMENS

https://www.youtube.com/watch?v=BtaAp_wTr7E
Induction charging solution
Without any contact

Static
- Already tested (Nguyen et al., 2015)
  (Pérez et al., MC2016) ...
- Almost ready for the future...

Dynamic / Main benefits for vehicles
- Time... no needs to park the EVs
- Smaller and lighter batteries (Seugmin et al., 2015)

Still Pb to solve from M&S pt of vue!

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Outlines

1. Intro / Context
2. M&S pavement needs: asphalt tRoads → eRoads
3. M4-5nW developments for eRoad analysis
4. Results and 1 alternative M&S eRoad proposal
5. Conclusion & Prospects
Box inclusion (CC material) in asphalt pavements

Charging Unit (CU) slab

Lateral loads effects

Solution proposed by (Chen, PHD 2016, 2017)


- \( E_{\text{layer}} / E_{\text{CU}} \rightarrow (T^\circ \text{C}, \text{Load speed}) \)
- Boundary conditions

Any cables somewhere?

(Chen, PHD 2016, 2017)
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Debonding criteria? Why?

Interface stresses (2D strain plane)

\[ j^{1,2}(x) = \begin{cases} 
zz(x, h^1_1) = zz(x, h_2) \\
xx(x, h^1_1) = xx(x, h_2) 
\end{cases} \]

Material 1

Material 2

(Pouteau et al., 2002, 2004)
Debonding criteria?

Why?

For homogeneous material ok!

\[
\bar{\sigma} = \frac{K_I}{\sqrt{r}} f_I(\theta) + \frac{K_{II}}{\sqrt{r}} f_{II}(\theta) + \cdots
\]

\[G(\bar{\sigma}, \bar{u}) = -\frac{\partial E_p(\bar{\sigma}, \bar{u}, a)}{\partial a}\]

\[G < G_c\]

\[U(x_1, x_2) = U(O) + kr^\lambda u(\theta) + \cdots\]

The critical value \(k_c\) depends on the opening \(\omega\) of the notch, it must be experimentally determined. The factors \(k\) and \(k_c\) are strongly dependent of the singularity and in particular of the exponent \(\lambda\). Units for

For bi-material, it is worst, \(\lambda\) can be a complexe field

\(E_1, \nu_1\)  
\(E_2, \nu_2\)

- Point stress?
- Average stress?
- Energy release rate -> fatigue...: Paris law?
Multi-particle Model of Multi-layer Materials (M4) – 5n (Chabot, 1997)

- Polynomial approximation per layer i in z for $\sigma_{ij}$
- Hellinger-Reissner formulation (Reissner, 1950)

For pavements (Tran et al., RILEM CP2004) (Chabot et al., BLPC2005) etc
M4-5nW 2D tool
(Nasser, PHD 2016) (Nasser and Chabot, 2018)

2D Problem $\rightarrow$ only 1D system to solve with matrix (12,12)

$$AX''(x) + BX'(x) + CX(x) = DY^{0,1'}(x) + EY^{n,n+1'}(x) + FY^{0,1}(x) + GY^{n,n+1}(x)$$

$$X = \begin{bmatrix} X^1 \\ X^2 \\ X^3 \\ X^4 \end{bmatrix}_{12 \times 1}$$

$$[X^i] = \begin{bmatrix} U^i_1 \\ \phi^i \\ U^i_3 \end{bmatrix}$$

$$[Y^{i,i+1}] = \begin{bmatrix} T^{i,i+1} \\ \nu^{i,i+1} \end{bmatrix}$$

Numerically $\rightarrow$ Newmark method

$$\frac{X_{j+1}^l + X_j^l}{2} = \frac{X_{j+1} + X_j}{k_{j+1}}$$


$$U_1(x,z) = U^i_1(x) + (z - \bar{h}_i)\phi^i_1(x) + \Delta U^i_1(x)$$
Introducing the material discontinuity (Deep, 2017)

\[ A^I X''(x) + B^I X'(x) + C^I X(x) = D^I Y^{0,1'}(x) + E + F^I Y^{0,1}(x) + G^I Y^{n,n+1}(x) \]

For zone with index I (CU)

1. Discretization posed issues as derivatives: in Newmark scheme used left and right nodes
2. All the matrices relating to zone 1 was to be modified in the code even before discretization, after discretization and for post processing

After discretization

\[ AX(x) = BY^{0,1}(x) + CY^{n,n+1}(x) + D \]
Crack discretization

For layer 2

$$A^I X''(x) + B^I X'(x) + C^I X(x) = D^I Y^{0,1'}(x) + E^I Y^{n,n+1'}(x) + F^I Y^{0,1}(x) + G^I Y^{n,n+1}(x)$$

Introducing material discont. & 1 vertical crack

(Deep, 2017)

Layer 2 stresses around this node are zero

$$N_{11}^2(X_f) = 0$$
$$M_{11}^2(X_f) = 0$$
$$Q_{1}^2(X_f) = 0$$

For layer 2

Boundary condition on the left and right at the point of crack and so changes are made in the system

$$AX(x) = BY^{0,1}(x) + CY^{n,n+1}(x) + D$$
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2D comparison
M4-5nW vs (Chen, 2016) for tRoad

\[ w=0, \quad E^1 = 1000\text{MPa} = E^2 \]

The material in the first layer is at more than 30°C at 10 Hz
When the material in box is same as in layer, results match.
Results due to load wandering at \( w = -0.2 \), \( E_1 = 1000 \text{MPa} = E_2 \)
Introducing the vertical crack
Results at \( w=0 \)

High interface stresses in case of vertical crack at \( w=0 \)

\[ n_{1,2} (x) = s_{33} x, h_1 + (\ldots) = s_{33} x, h_2 - (\ldots) \]
Adaptation of tRoads for eRoads?

- Base course
- Sub-base course
- Surface course
- Base course
- CU slab 14cm
- Base course
- Sub base
- CU slab
- Sub grade
- Sub base
- Sub grade
Proposal
1 solution for the Adaption of tRoads

Why not using composite pavement such as UTW?
Knowing that Cement concrete (CC) overlaid on asphalt has a good bond (such as in UTW pavement) (Silfwerbrand, 1998) (Pouteau et al., 2004) (Rasmussen et al., 2004) (Hun et al., CP2012) (Chabot et al., 2008, 2013, 2017) (Barman et al., 2017) (Mateos, 2017), ...

Joints → cables
\[ n_{1,2}(x) = s_{zz}(x, h_1) + \frac{1}{2} = s_{zz}(x, h_2) - \frac{1}{2} \]

\[ n_{2,3}(x) = s_{zz}(x, h_2) + \frac{1}{2} = s_{zz}(x, h_3) - \frac{1}{2} \]
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eRoad PB tested with viscoelasticity model in (Chen, 2016), here discontinuities are studied between the CU & material layer

A better access to interface stress field plays for a better understanding of the PB $\Rightarrow$ need to use alternative modeling

**Prospects**

- Use of M4-5n 3D new development with FreeFem++ code (Nasser et al., 2018) $\Rightarrow$ Partial debonding boundary conditions
- Lateral loading study according to (Hammoum et al., 2010)
- Thermal gradient effect studies specially for the use of top layers made with CC materials as done by (Chabot et al., 2005)
Thanks for your attention

apt 2020
Accelerated Pavement Testing
6th international conference
September 21-23, 2020
Nantes, FRANCE

Save the dates!
apt2020.sciencesconf.org
Prise en compte de décollement d’interface

Rendre les efforts d’interface nuls sur la surface décollée
Idem : dédoublement des nœuds sur contour de la surface décollée

Initial problem structure

2D mesh (M4-5n)

Material layer 3
Material layer 1
Material layer 2

Debonding

Node doubled
M4-Boussinesq results (Tran, 2004)

Example of a cracked bi-layers pavement with thermic effects in the Layer 2