FABRIC

Feasibility analysis and development of on-road charging solutions for future electric vehicles

Civil engineering aspects of e-Roads

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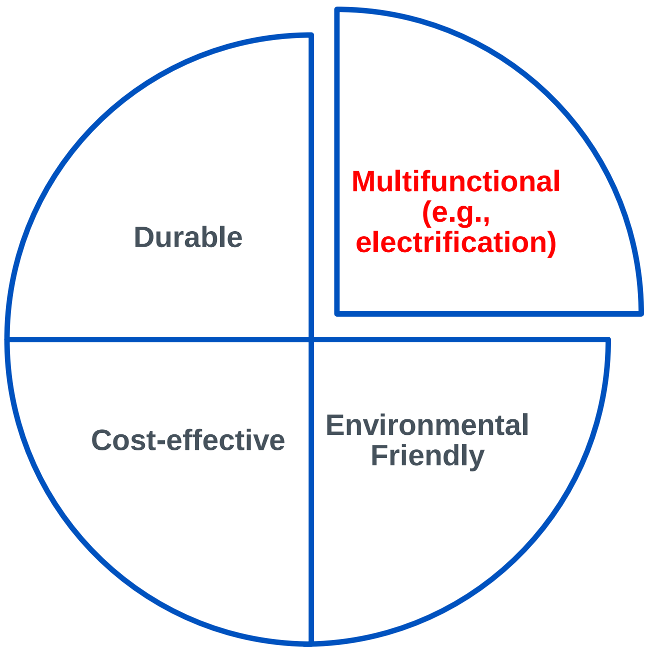
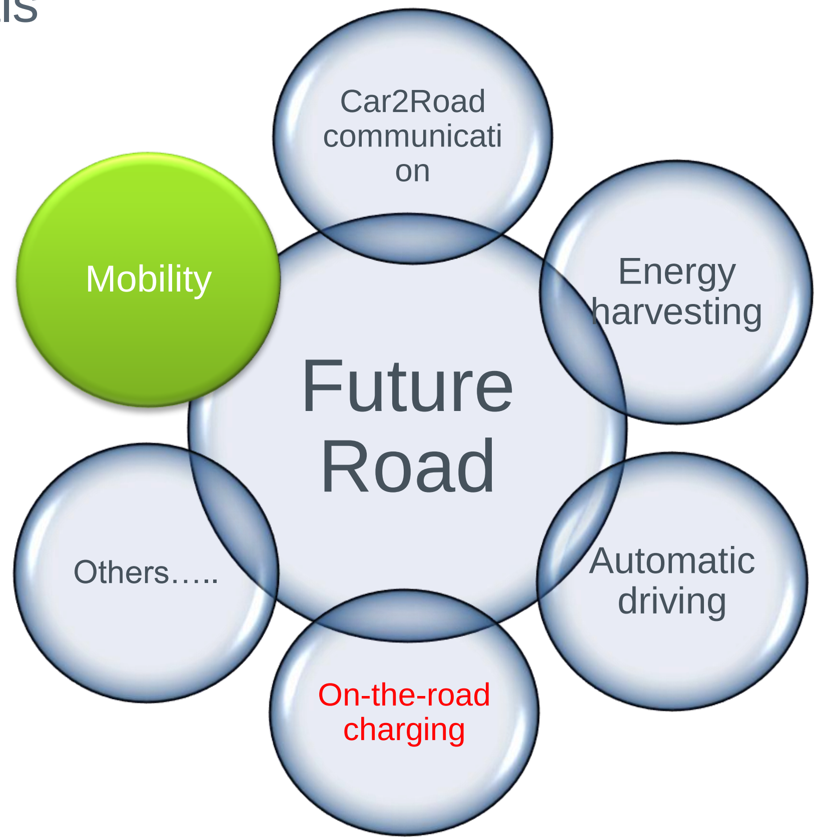
2018-06-21

1. Introduction

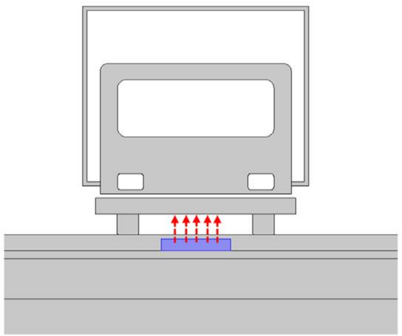
- ❑ A vision of our future roads (smart & multifunctional)
- ❑ Civil engineering considerations in Electrified Roads
  - Road structure and materials





2. Structural aspect of e-Roads

- Various e-Road power transfer solutions under active development



(a) Inductive Power Transfer

(b) Conductive Rail

(c) Pantograph

- Road structural design and optimization
  - In-situ Installation
  - Prefabrication-based Installation

Examples of e-Road construction ways (OLEV, South Korean) (*Photographs courtesy of Dongwon, OLEV*)

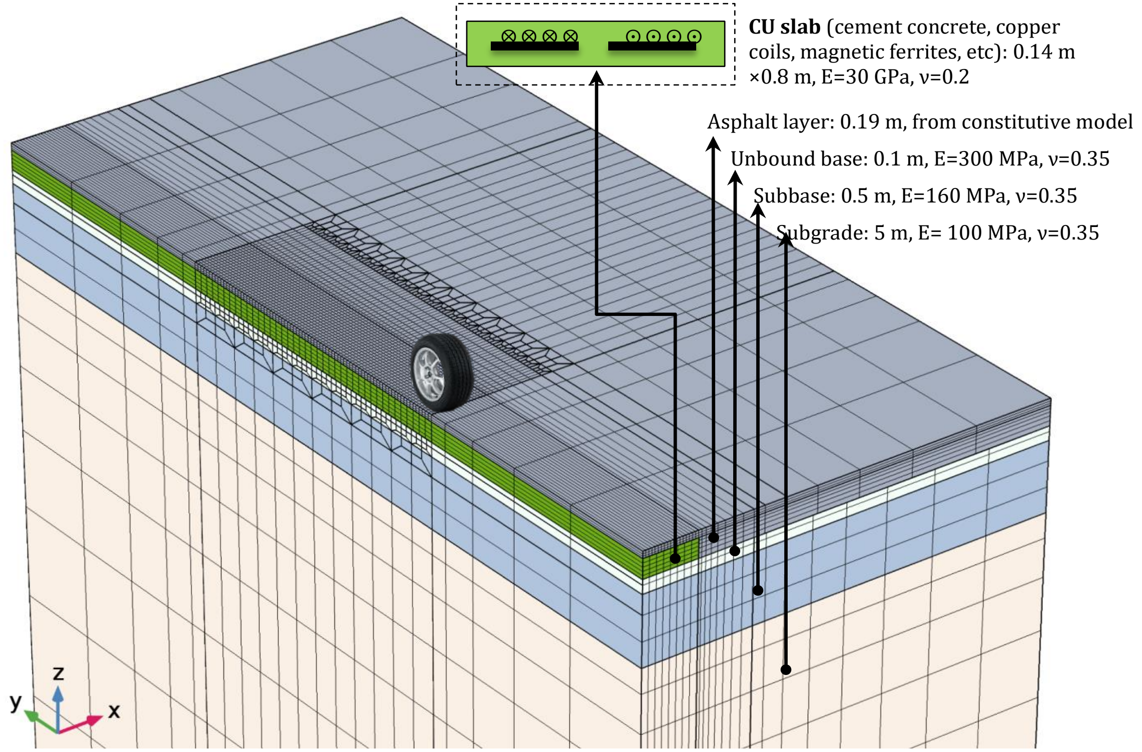
2. Structural aspect of e-Roads

1. Important questions include:
   - Will eRoads remain durable with new objects embedded?
     - In vertical and horizontal planes
   - Will eRoads require new construction methods and materials?
   - What are the consequences for maintenance intervals and methods?

2. Simulation studies performed to provide insights in strains and stress
3. Laboratory tests performed on sample constructions

2. Structural aspect of e-Roads

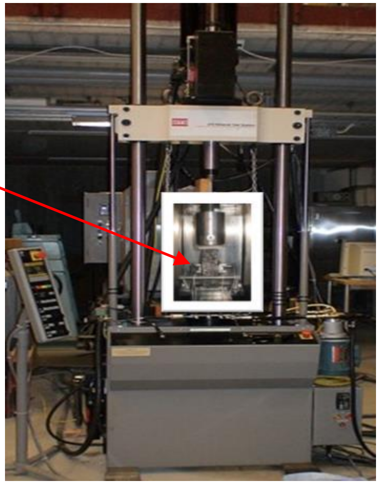
- E-Road structural performance prediction and analysis
  - Finite Element (FE) modelling and simulation
    - Model construction

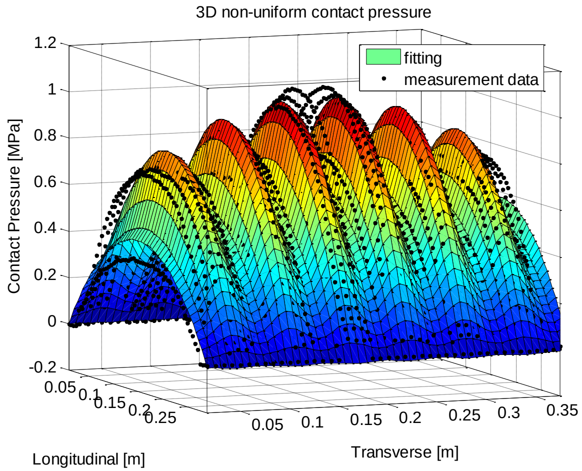


Example of FE model construction for e-Road structural representation

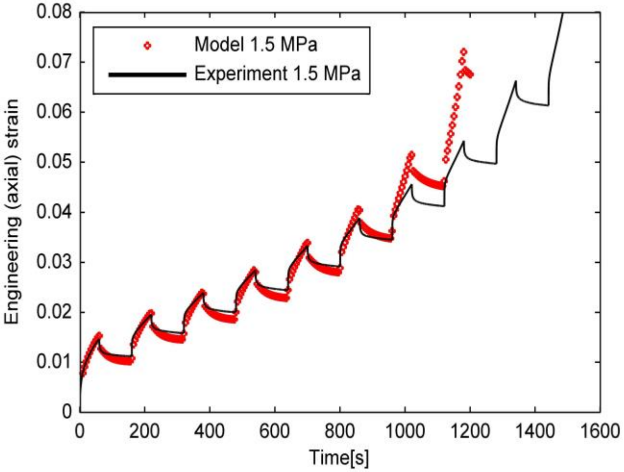
2. Structural aspect of e-Roads

- E-Road structural performance prediction and analysis
  - Important inputs for FE simulation
    - Realistic loading conditions
    - Asphalt material model
      (visco-elasticity, visco-plasticity, damage)





Example of realistic tire-pavement contact pressures

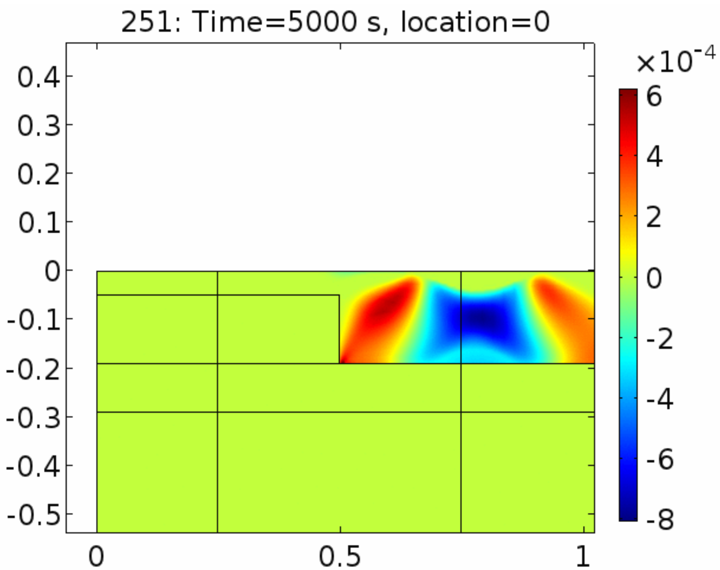


Example of asphalt material model calibration and validation

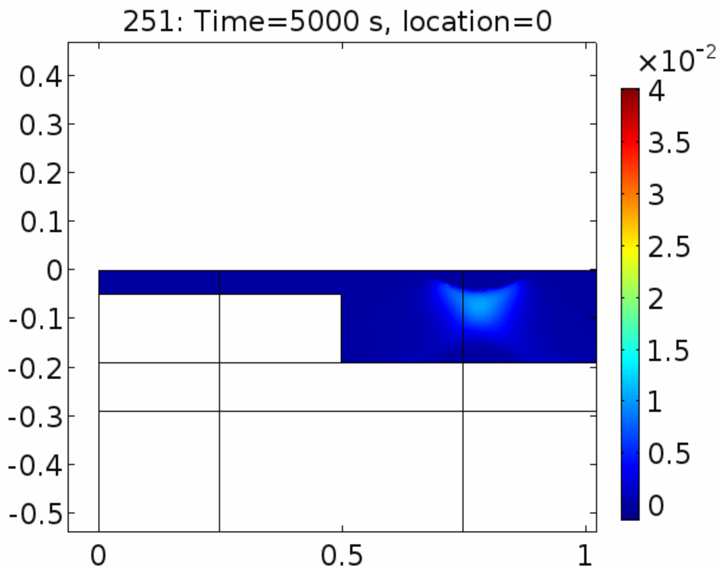
2. Structural aspect of e-Roads

- E-Road structural performance prediction and analysis
  - Example 1: Influence from continuously traffic loading
    - » Deformations and damages

Distributions of plastic strain E_{yy}



Distributions of damage variable D



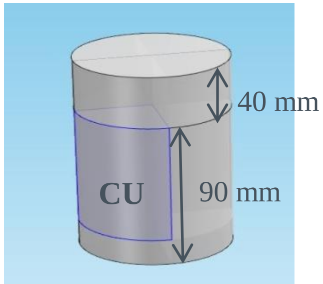
2. Structural aspect of e-Roads

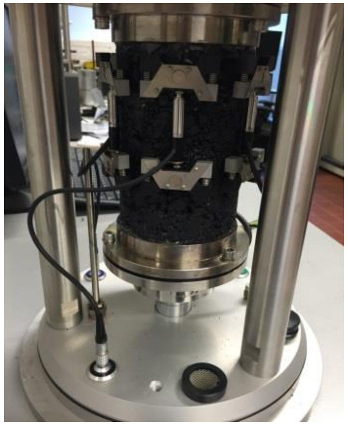
- E-Road structural performance prediction and analysis
  - Example 1: Influence from continuously traffic loading
    - » Deformations and damages
      - **Accelerated loading test on small scale E-Road sample**

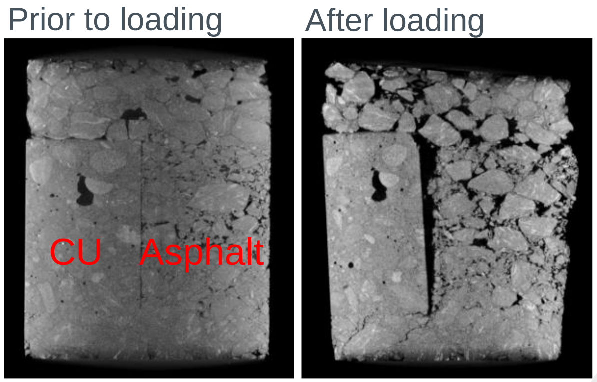
E-Road sample design → Accelerated loading test → X-Ray scanning test

- Experimental reproduction of critical zones in E-Road structure

- Vertical load (800 kPa, 0.1 s), 1e4 cycles
- Confinement load (140 kPa, constant)







2. Structural aspect of e-Roads

- Some important findings:
  - Weak locations lie mainly in the asphalt regions close to the intersection with the Charging Unit (CU).
  - It is possible to reduce damage concentrations through proper optimization on, e.g., the geometry and material properties of the CU, and embedment depth.
  - Significant loss of bonding property (adhesion) at the CU-asphalt interface could notably intensify the tensile and shear strains in asphalt overlay of e-Road.
  - Tire braking and accelerating actions could incur higher potential of surface related distresses in e-Road, which could be further aggravated due to the loss of interface bonding.
  - Improvement in E-Road structural integrity is of great importance, which include uses of: 1) high-quality coatings, stress-relief membranes or fabrics, and plug joint materials at the critical interfaces; and 2) reinforced materials and gradation of asphalt overlay.
  - The changed vehicle behavior could affect the pavement performance significantly. For instance, reduced wheel wander and decreased vehicle speed could would accelerate the rutting deformations.

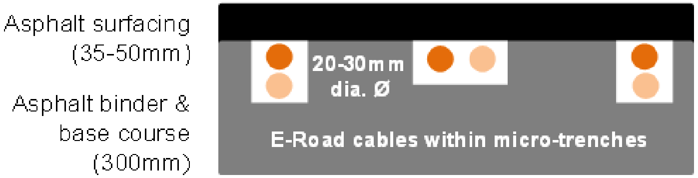
3. Construction of e-Roads

- Technologies are under development, either in an in-situ-based or prefabrication-based installation.

1. Trench-based way

(images courtesy of Dongwon OLEV)

2. Micro-trench way



(images courtesy of TRL)

3. Full lane replacement

(images courtesy of Bombardier)

3. Construction of e-Roads

- Construction of e-Roads
  – Comparisons in different solutions (Table in courtesy of TRL)

Construction	Advantages	Drawbacks
Trench construction	- Relatively quick construction - Lowest initial construction costs - Would only require one lane closure - few vehicle movements & fill volumes are low	- Likely higher future maintenance and whole life costs - Would introduce two longitudinal joints in centre of the lane, and transverse joints for power supply
Micro-trench excavation and fill	- Relatively quick installation periods - Low volume of waste material excavated - Little compromise to the structural integrity - Ease of access for maintenance/replacement	- Likely higher future maintenance and whole life costs - Would introduce two longitudinal joints in centre of the lane, and transverse joints for power supply
Full lane width reconstruction	- Single longitudinal joint(s) at lane interface(s) - Likely lower life costs than trench construction - Potential to reuse planed off asphalt	- Slow construction - Requires 2 lanes of traffic management - Relatively high vehicle movements
Full lane width replacement with pre-fabricated section	- Relatively quick installation - High quality, factory construction - Single longitudinal joint(s) at lane interface(s) - Moderate vehicle movements - Lower whole life costs	- High initial cost & increased construction time - Potential maintenance issues with transverse joints - Disruption to road users due to transport - Precast slabs prone to movement under loading - Requires 2 lanes of traffic management - Strict joint maintenance program required

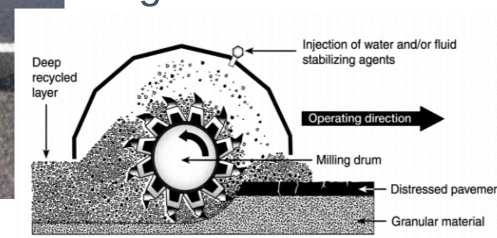
4. Maintenance and monitoring of e-Roads

- Type and timing of maintenance activities, equipment, cost estimations, practical implementations..

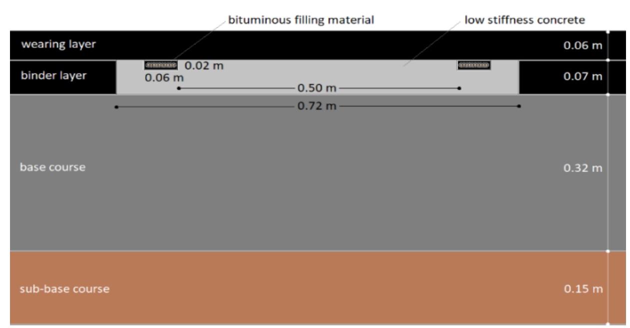
Preventive maintenance

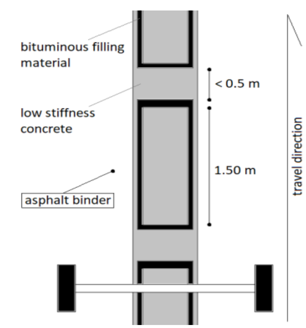
Resurfacing

Large rehabilitation



What about the e-Road?





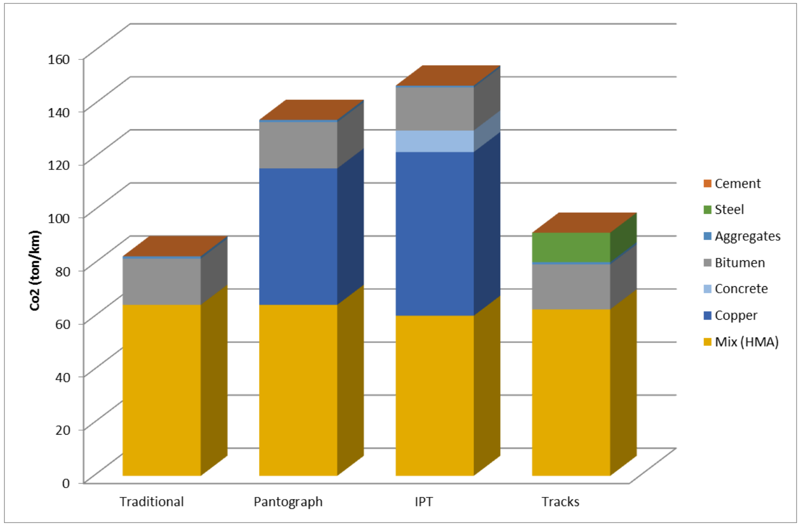
Example of e-Road using POLITO technology: Cross section (left) and top view (right)

4. Maintenance and monitoring of e-Roads

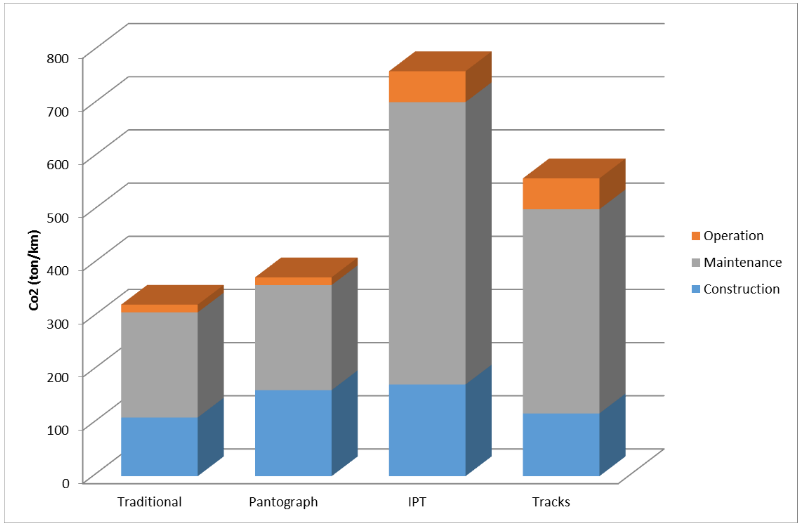
- Some major considerations for e-Roads:
  - Monitoring of e-Road conditions is possibly more important than in a T-Road, which may include: 1) more frequent visual survey of e-Road pavement degradations and foreign objects, and 2) increased use of devoted monitoring device/instruments to, automatically and non-destructively, detect the degradations.
  - Maintenance: 1) The maintenance operations of e-Roads should, as much as possible, comply with the standard methods for the T-Roads. 2) The maintenance activities may strongly relate to the construction method. 3) Maintenance frequency, and thus the costs and traffic interferences, may increase in e-Road, especially at stops and intersections. 4) Closer collaboration between road team and technology team is needed on unexpected maintenance of the CU.
  - Rehabilitation actions: 1) Finer milling should be performed when approaching the CU, to avoid coil damages. 2) Adequate coating at the interfaces is needed to delay the damage risk. 3) Use of recycled materials in e-Road should be more cautious.

5. Sustainability of e-Roads

- Assessment of life cycle impacts of e-Roads
  - Example: Impacts (CO_2) of different e-Road solutions during:
    - » material production stage
    - » construction, operation and maintenance stages



CO_2 production of e-Road solutions during the infrastructural material production stage



CO_2 production of e-Road solutions during the construction, operation and maintenance stages.

6. Concluding remarks

- Challenges in civil engineering of e-Roads:
  - E-Road is structurally more complex than a traditional road (T-Road), and its performance is more difficult to be adequately predicted.
  - Optimization of e-Road structural and material design is of great importance, and should be further researched.
  - Common practices in construction, maintenance and monitoring, end-of-life recycling need to be properly adjusted for e-Roads.
  - E-Road infrastructure produces higher life cycle environmental impacts than a traditional road, especially during maintenance. This has been further integrated into the life cycle assessment of the whole system.
- Opportunities co-exist in civil engineering of e-Roads:
  - Opening up possibilities in developing new road materials and pavement structures, which are currently economically unviable.
  - Integrating the infrastructure into the sustainable development of road transport as a whole.

List of involved publications (KTH & POLITO)

Journals

1. Chen F, Balieu R, Kringos N. et al. Structural performance of electrified roads: A computational analysis. Journal of Cleaner Production, in press, 2018.
2. Chen F, Taylor N, Kringos N. Dynamic applications of the Inductive Power Transfer (IPT) systems in an electrified road: Dielectric power loss due to pavement materials. Construction and Building Materials, 2017, 147: 9-16.
3. Chen F, Balieu R, Córdoba E, Kringos N. Towards an understanding of the structural performance of future electrified roads: a finite element simulation study. International Journal of Pavement Engineering, 2017, DOI: 10.1080/10298436.2017.1279487.
4. Chen F, Taylor N, Kringos N. Electrification of roads: Opportunities and challenges. Applied Energy, 2015, 150: 109-119.
5. Ceravolo, R., Miraglia, G., & Surace, C. (2017). Strategy for the maintenance and monitoring of electric road infrastructures based on recursive lifetime prediction. Journal of Civil Structural Health Monitoring, 7(3), 303-314.
6. Ceravolo, R., Miraglia, G., Surace, C., & Zanotti Fragonara, L. (2016). A Computational Methodology for Assessing the Time-Dependent Structural Performance of Electric Road Infrastructures. Computer-Aided Civil and Infrastructure Engineering, 31(9), 701-716.

Conference proceedings:

7. Chen F, Balieu R, Kringos N. Sustainable implementation of future smart road solutions: a case study on the electrified road. In Proceedings of 10th International Conference on the Bearing Capacity of Roads, Railways and Airfields, Athens, Greece, 2017.
8. Córdoba E, Chen F, Balieu R, Kringos N. Towards an understanding of the structural integrity of electrified roads through a combined numerical and experimental approach. In Compendium of 96th annual meeting of Transportation Research Board, Washington D.C., 2017.
9. Chen F, Birgisson B, and Kringos N. Electrification of Roads: An infrastructural perspective. Compendium of the 94th Annual Meeting of Transportation Research Board, Washington D.C., 2015.
10. Chen F, Kringos N. Towards new infrastructure materials for on-the-road charging. Electric Vehicle Conference (IEVC), 2014 IEEE International. IEEE, 2014: 1-5.
11. Ceravolo, R., Miraglia, G., Pinotti, E., Surace, C., & Zanotti Fragonara, L. (2015). Modelling of a road infrastructure adapted for dynamic inductive recharging for maintenance and monitoring.
12. Ceravolo, R., Miraglia, G., & Surace, C. (2017). Fatigue damage assessment of electric roads based on probabilistic load models. Paper presented at the Journal of Physics: Conference Series.
13. Ceravolo, R., & Surace, C. (2016). Strategies for Assessing the Structural Performance of Electric Road Infrastructures. Paper presented at the 6th Civil Structural Health Monitoring (CSHM-6) annual ISHMII workshop, Belfast, Ireland.

FABRIC

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Thank you!

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