Assessment of in-situ compaction degree of HMA pavement surface layers using GPR and novel dielectric properties-based algorithms

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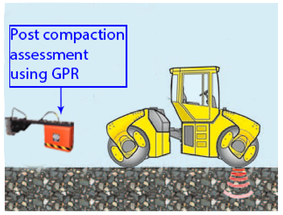
Objectives- Research scope



Assessment of in-situ compaction degree of HMA surface layer

- GPR
  - ALL model
  - Finnish (PANK)
  - Regression-based
- PQI
- Field cores
  - Mean Absolute Percent Error (MAPE)

Evaluation of number of calibration cores

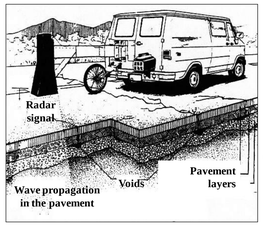
Evaluation of antenna frequency (1Ghz vs 2 GHz)

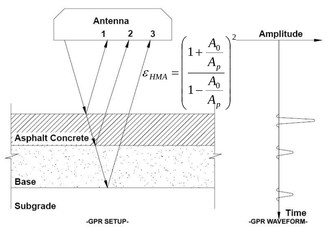
Ground Penetrating Radar (GPR)

an intelligent sensor technique that has led to a powerful Non-Destructive Testing (NDT) method for road pavement evaluation.

▪Recent improvements in hardware and in particular software processing have contributed to the rapidly expanding popularity and usability of this technique in the pavement engineers community.

▪GPR has been defined as both a technically feasible and promising method for the nondestructive, rapid, and continuous evaluation of in-situ asphalt pavement density based on electromagnetic mixing (EM) theory.





GPR

- Antenna transmits & receives electromagnetic energy
- Reflection at boundaries between materials of different electric permittivity
- Ability to store a molecular charge
- The larger the difference, the greater the reflection
- Travel time is measured
- Subject to interpretation

The ALL model:

prediction of asphalt mixture density based on bulk electric permittivity as measured by the GPR, the dielectric properties of the asphalt mix materials, as well as other material information.

$$G_{mb} = \frac{\frac{\varepsilon_{HMA}-\varepsilon_b}{3\varepsilon_{HMA}-2.3\varepsilon_b} - \frac{1-\varepsilon_b}{1-2.3\varepsilon_b+2\varepsilon_{HMA}}}{\left(\frac{\varepsilon_s-\varepsilon_b}{\varepsilon_s-2.3\varepsilon_b+2\varepsilon_{HMA}}\right)\left(\frac{1-P_b}{G_{se}}\right)-\left(\frac{1-\varepsilon_b}{1-2.3\varepsilon_b+2\varepsilon_{HMA}}\right)\left(\frac{1}{G_{mm}}\right)}$$

where:

G_{mm}	maximum specific gravity
G_{se}	effective specific gravity of aggregate
G_b	specific gravity of binder
P_b	binder content [%]
ε_{HMA}	electric permittivity of asphalt mixture
ε_b	electric permittivity of binder
ε_s	electric permittivity of aggregate

Finnish (PANK) algorithm:

prediction of asphalt mixture air voids based on bulk electric permittivity as measured by the GPR and determination of calibration coefficient..

$$\text{Air Voids (\%)} = 272.93 * e^{-1.3012 * k * \varepsilon_{HMA}}$$

Regression-based algorithm:

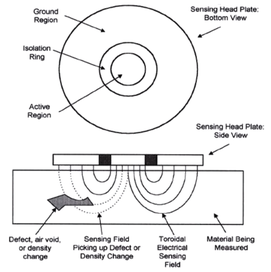
prediction of asphalt mixture density based on bulk electric permittivity as measured by the GPR and determination of calibration coefficients.

$$\rho_b = a * e^{b * \varepsilon_{HMA}}$$

Pavement Quality Indicator (PQI):

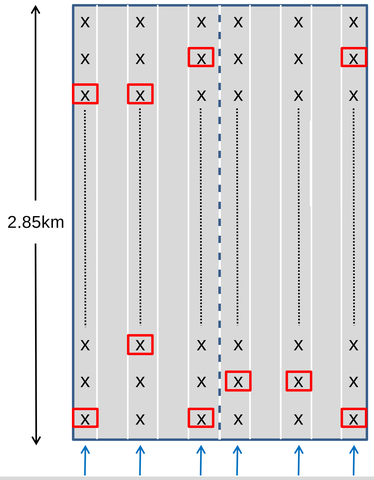
▪This approach is based on a novel toroidal electrical sensing field that is established in the material to be measured via a flat sensing plate.

▪Density, or compaction degree, is measured by the response of the PQI's electrical sensing field to changes in electrical impedance of the material matrix, which in turn is a function of the composite dielectric constant of the paving material and the air trapped in the voids of the material.



Field experiment

- GPR measurements using 1 and 2 Ghz Antenna
- Estimation of HMA electric permittivity values (ε_{HMA})
- In situ density measurements using PQI (electromagnetic method)
- Extraction of cores (in total 20) and determination in lab of surface layer density (SSD method)



X PQI test points (per 200m)

X PQI test points and core locations

GPR test lines

Data analysis and results

GPR measurements data (1 & 2 Ghz antenna)

Estimation of ε_{HMA}

Field cores (lab) density (for *n=3, 4…9*)

Calculation of algorithms coefficients

- ALL model: ε_s
- Finnish (PANK): k
- Regression- based: a, b

Prediction of density of remaining cores/ Evaluate each method error performance

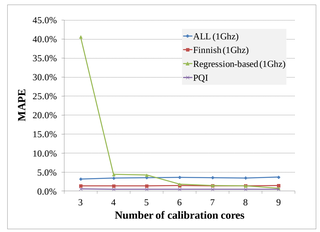
PQI measurements data

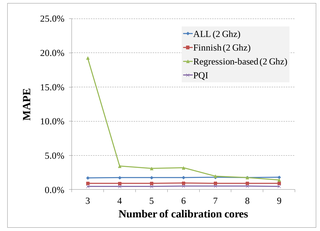
Field cores (lab) density (for *n=3, 4…9*)

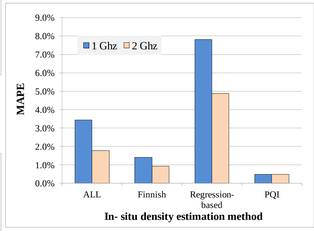
Calibration of PQI data Offset calculation

Density estimation of remaining cores/ Evaluate method error performance

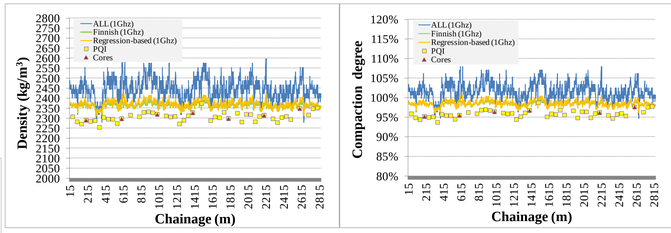
A) Evaluation of number of calibration cores with respect to antenna frequency

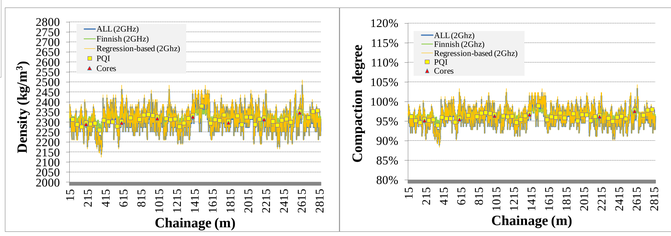






B) Assessment of in-situ compaction degree





Conclusions

- ❑ Regression-based method error prediction performance is improved significantly with the increase of number of calibration cores
- ❑ Both, the ALL and Finnish (PANK) model error prediction performance does not seem to be improved with the increase of number of calibration cores
- ❑ A limited number (on the order of seven) of cores seems to be sufficient to yield acceptable error performance for all GPR-based algorithms
- ❑ Implementing the GPR-based algorithms more accurate results were obtained using the 2 Ghz antenna
- ❑ The PQI method was found to outperform the GPR-based methods, although this method provides information only at discrete test locations
- ❑ Generally, the GPR-based algorithms could be used to assess rather accurately the in-situ compaction degree of HMA pavement surface layer