TU1208 GPR Association Training School on Ground Penetrating Radar for Civil Engineering and Cultural Heritage Management

Training School

Roma, Italy
14-18 May,2018

Sapienza University of Rome

GPR Activities in Croatia with a Main Focus on Research Projects Carried out at the University of Split, TWiNS II Electromagnetic Simulation Tool by the University of Split: Theoretical Background and Practical Use

Dragan Poljak, Anna Šušnjara (Croatia)

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GPR Activities in Croatia

- Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split

- Faculty of Civil Engineering, University of Osijek

- Faculty of Civil Engineering, Architecture and Geodesy, UnIversity of Split

- Faculty of Civil Engineering, University of Zagreb

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Action TU1208
Civil Engineering Applications
of Ground Penetrating Radar

Theoretical Background of SuZANA and TWiNS II codes – Frequency Domain Analysis

Training School

Roma, Italy
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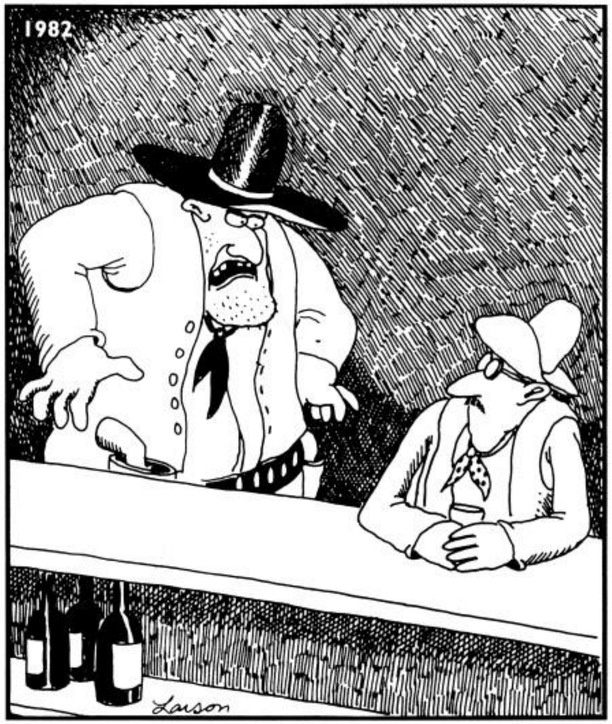
Talk Layout



"I asked you a question, buddy. … What's the square root of 5,248?"

- Introduction
- Formulation
- Numerical Solution
- Concluding Remarks
- References and Author's Bio

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Introduction

About SuZANA and TWiNS codes

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INTRODUCTION

- **SuzANA** (in Croatian: **S**ustav **za** **A**nalizu **N**izova **A**ntena – System for the Analysis of Antenna Arrays) and **TWiNS** (**T**hin **Wi**re **N**umerical **S**olver) are user friendly software packages for the analyis of radiation and scattering from thin wires developed at the University of Split, FESB by: Dragan Poljak, Vicko Dorić, Sinisa Antonijevic and Anna Susnjara.
- Using these codes the analysis can be carried out in both frequency domain (FD) and time domain (TD).
- FD analysis is based on the FD Pocklington integro-differential equation, while the TD analysis is based on the TD Hallen integral equation and corresponding radiated field formulas.

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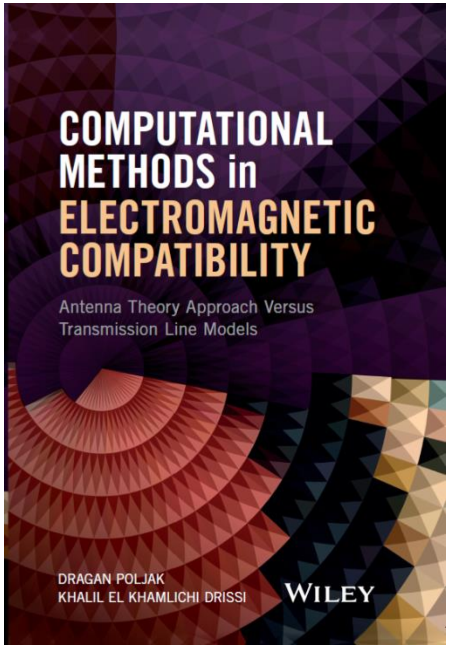
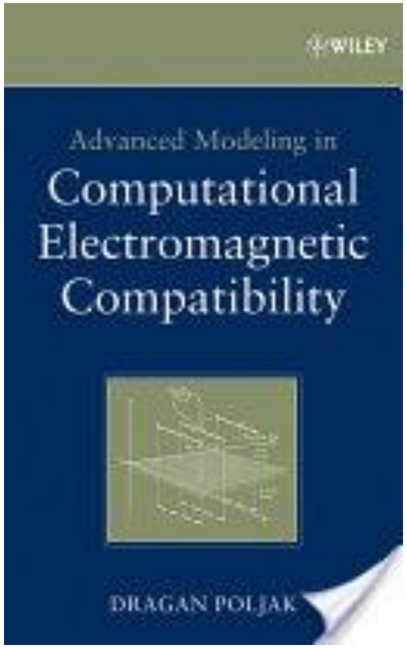
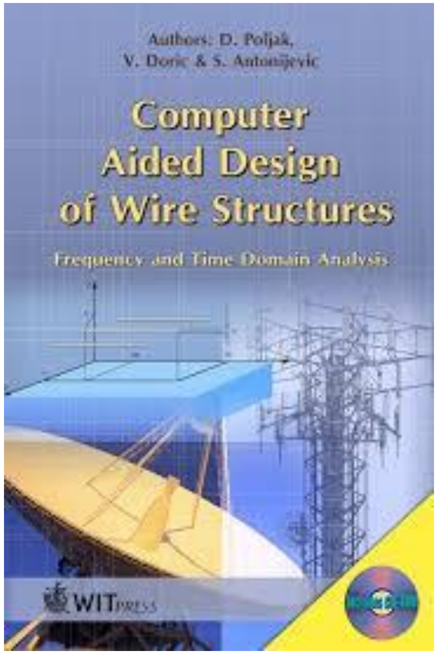
INTRODUCTION

- The integral expressions are handled by means of FD and TD scheme of the Galerkin – Bubnov Indirect Boundary Element Method (GB-IBEM).
- The corresponding reflected/transmitted field is obtained by numerically computing the related field integrals.







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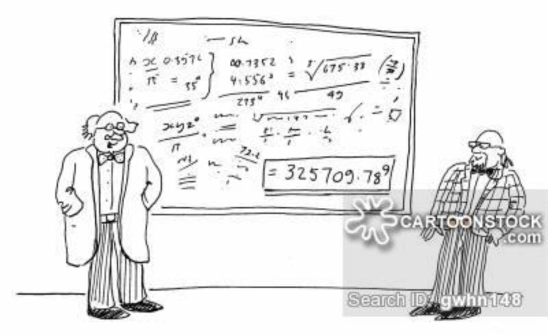
Formulation

Derivation of Pocklington equation and field integral formulas



"Wow! Amazingly that's my lucky number!"

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FORMULATION

- The formulation is based on the space-frequency integro-differential equation of the Pocklington type and corresponding filed formulas.
- The presence of the air-ground interface is taken into account via corresponding reflection/transmission coefficients.
- The space-frequency Pocklington equation is numerically solved via the Galerkin-Bubnov variant of the Indirect Boundary Element Method (GB-IBEM).
- The corresponding reflected/transmitted field is obtained by numerically computing the related field integrals.

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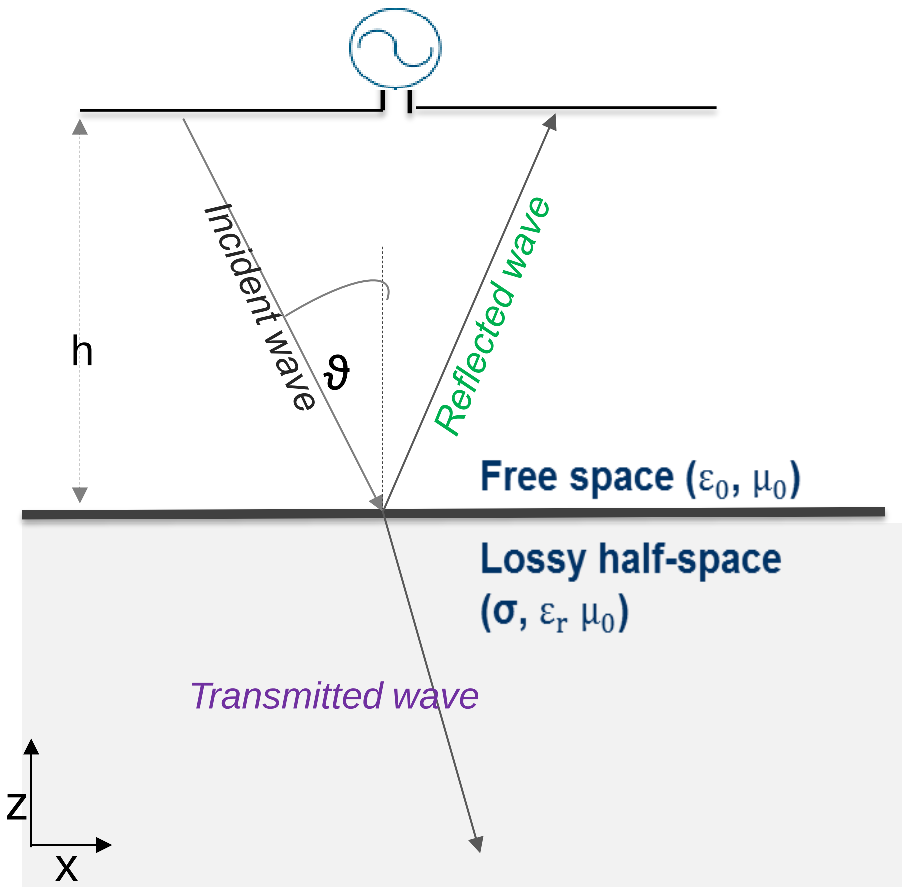
FORMULATION

- Geometry of interest – dipole antenna above a lossy ground



FORMULATION

- Interface conditions for the tangential components of the E-field at the PEC wire:

$$\vec{e}_x \cdot \left(\vec{E}^{exc} + \vec{E}^{sct}\right) = 0$$

- The excitation:

$$\vec{E}^{exc} = \vec{E}^{inc} + \vec{E}^{ref}$$

- Scattered field:

$$\vec{E}^{sct} = -j\omega\vec{A} - \nabla\varphi$$

- Thin wire approximation (TWA):

$$E_x^{sct} = -j\omega A_x - \frac{\partial\varphi}{\partial x}$$

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FORMULATION

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- **Scalar potential:**

$$\varphi(x) = -\frac{1}{j4\pi\omega\varepsilon_0}\int_{-L/2}^{L/2}\frac{\partial I(x')}{\partial x'}g(x.x')dx'$$

- **Vector potential:**

$$A_x = \frac{\mu}{4\pi}\int_{-L/2}^{L/2} I(x')g(x.x')dx'$$

- **Pocklington's integro-differential equation:**

$$\boxed{E_x^{exc} = j\,\omega\frac{\mu}{4\pi}\int_{-\frac{L}{2}}^{\frac{L}{2}} I(x')g(x,x')dx' - \frac{1}{j4\pi\omega\varepsilon_0}\frac{\partial}{\partial x}\int_{-\frac{L}{2}}^{\frac{L}{2}}\frac{\partial I(x')}{\partial x'}g(x,x')dx'}$$

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FORMULATION

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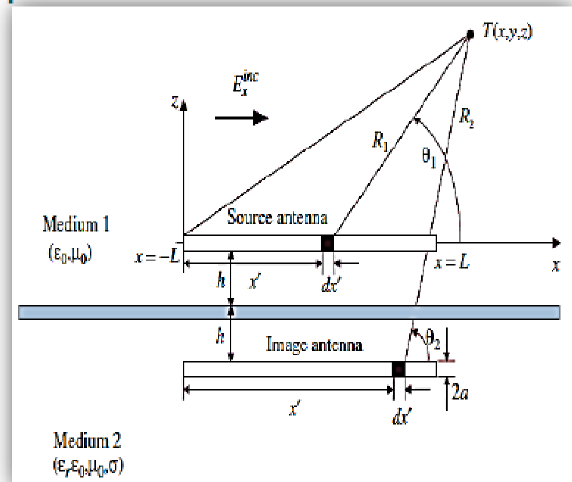
- Pocklington's integro-differential equation:

$$E_x^{exc} = j\,\omega \frac{\mu}{4\pi}\int_{-\frac{L}{2}}^{\frac{L}{2}} I(x')\,g(x,x')\,dx' - \frac{1}{j4\pi\omega\varepsilon_0}\frac{\partial}{\partial x}\int_{-\frac{L}{2}}^{\frac{L}{2}} \frac{\partial I(x')}{\partial x'}\,g(x,x')\,dx'$$



Total Green's function:

$$g(x,x') = g_0(x,x') - R_{TM}\cdot g_i(x,x') \qquad g_0(x,x') = \frac{e^{-jk_0R_0}}{R_0} \qquad g_i(x,x') = \frac{e^{-jk_0R_i}}{R_i}$$

Fresnel's reflection coefficient:

$$R_{TM} = \frac{n\ \cos\vartheta - \sqrt{n-(\sin\vartheta)^2}}{n\ \cos\vartheta + \sqrt{n-(\sin\vartheta)^2}} \qquad n = \sqrt{\varepsilon_r - j\frac{\sigma}{\omega\varepsilon_0}} \qquad \theta = arctg\frac{|x-x'|}{2h}$$

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FORMULATION

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- The electric field above a lossy half space:

$$E_x = \frac{1}{j4\pi\omega\boldsymbol{\varepsilon_0}}\left[-\int_{-\frac{L}{2}}^{\frac{L}{2}} \frac{\partial I(x')}{\partial x'}\frac{\boldsymbol{\partial g(x,y,x')}}{\partial x}dx' + \boldsymbol{k^2}\int_{-L/2}^{L/2} I(x')\boldsymbol{g(x,x')}dx'\right]$$

$$E_y = \frac{1}{j4\pi\omega\boldsymbol{\varepsilon_0}}\int_{-\frac{L}{2}}^{\frac{L}{2}} \frac{\partial I(x')}{\partial x'}\frac{\boldsymbol{\partial g(x,y,x')}}{\partial y}dx'$$

$$E_z = \frac{1}{j4\pi\omega\boldsymbol{\varepsilon_0}}\int_{-\frac{L}{2}}^{\frac{L}{2}} \frac{\partial I(x')}{\partial x'}\frac{\boldsymbol{\partial g(x,y,x')}}{\partial z}dx'$$

Green function: $g(x,x') = g_0(x,x') - \boldsymbol{R_{TM}}\, g_i(x,x')$

Fresnel reflection coefficient:

$$g_0(x,x') = \frac{e^{-jk_0R_0}}{R_0} \qquad g_i(x,x') = \frac{e^{-jk_iR_i}}{R_i} \qquad \boldsymbol{R_{TM}} = \frac{n\cos\vartheta - \sqrt{n - (\sin\vartheta)^2}}{n\cos\vartheta + \sqrt{n - (\sin\vartheta)^2}}$$

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FORMULATION

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- **Tangential field transmitted into the ground:**

$$E_{x,tr} = \frac{1}{j4\pi\omega\varepsilon_{eff}}\left[-\int_{-\frac{L}{2}}^{\frac{L}{2}} \frac{\partial I(x')}{\partial x'}\frac{\partial \boldsymbol{G}(\boldsymbol{x},\boldsymbol{x'},\boldsymbol{z})}{\partial x'}dx' - \gamma^2\int_{-\frac{L}{2}}^{\frac{L}{2}} I(x')\boldsymbol{G}(\boldsymbol{x},\boldsymbol{x'},\boldsymbol{z})dx'\right]$$

Green function:

$$G(x,x',z) = \boldsymbol{\Gamma_{tr}^{MIT}}\, g(x,x')$$

Propagation constant

$$\boldsymbol{\gamma} = \sqrt{\boldsymbol{j\omega(\sigma + j\omega\varepsilon_0\varepsilon_r)}}$$

Transmission coefficient arising from from Modified Image Theory (MIT):

$$\boxed{\boldsymbol{\Gamma_{tr}^{MIT}} = \frac{\boldsymbol{2n}}{\boldsymbol{n+1}}}$$

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Numerical solution

Evaluation of the antenna current distribution and radiated field components

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NUMERICAL SOLUTION

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BEM solution of Pocklington equation system

- Local approximation for current : $$I(x') = I_{1i}\frac{x_{2i}-x'}{\Delta x} + I_{2i}\frac{x'-x_{1i}}{\Delta x}$$

- Global matrix equation: $$\sum_{k=1}^{N_e}[Z]_{pk}\{I\}_k = \{V\}_p$$

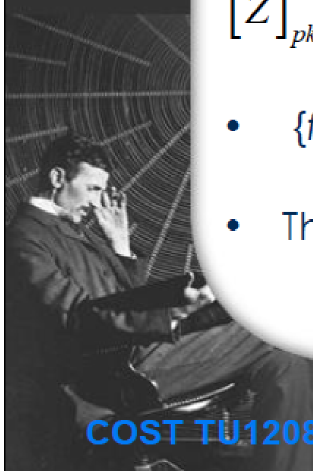
  N_e - the total number of elements

  The mutual impedance matrix:

$$[Z]_{pk}^{e} = -\int_{\Delta l_p}\int_{\Delta l_k}\{D\}_p\{D'\}_k^T g_{ji}(x,x')dx'dx + k^2\int_{\Delta l_p}\int_{\Delta l_k}\{f\}_l\{f'\}_k^T g_{ji}(x,x')dx'dx$$

- {*f*}, {*f'*} shape functions vectors, {*D*}, {*D'*} shape function derivatives

- The local voltage vector: $$\{V\}_p = -j4\pi\omega\varepsilon_0\int_{\Delta l_p}E_x^{inc}(x)\{f\}_p dx$$



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NUMERICAL SOLUTION – Case of free space

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- Shape are chosen from the family of Lagrange's polynomials

$$L_i(x) = \prod_{j=1}^{m} \frac{x - x_j}{x_i - x_j}, \quad j \neq i$$

- A linear case:

$$f_1(x) = \frac{x_2 - x}{\Delta x}$$

$$f_2(x) = \frac{x - x_1}{\Delta x}$$

- where x_1 and x_2 are the coordinates of the segment nodes and $\Delta x = x_2 - x_1$ is the semgemt length.

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NUMERICAL SOLUTION – Case of free space

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$K(I) = E$
$K(I) = E$

- $[Z]_{ji}$ and $\{V\}_j$ are given by:

$$[Z]_{ji} = \int_{\Delta l_j}\int_{\Delta l_i} \begin{bmatrix} \frac{df_1(x)}{dx}\frac{df_1(x')}{dx'} & \frac{df_1(x)}{dx}\frac{df_2(x')}{dx'} \\ \frac{df_2(x)}{dx}\frac{df_1(x')}{dx'} & \frac{df_2(x)}{dx}\frac{df_2(x')}{dx'} \end{bmatrix} g_0(x,x')dx'\,dx +$$

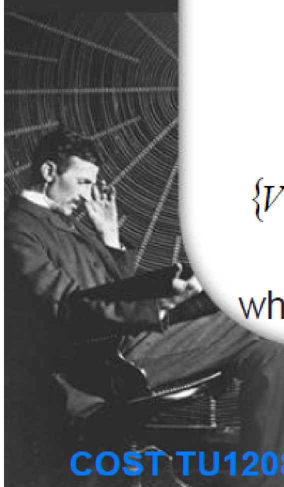
$$+k^2 \int_{\Delta l_j}\int_{\Delta l_i} \begin{bmatrix} f_1(x)f_1(x') & f_1(x)f_2(x') \\ f_2(x)f_1(x') & f_2(x)f_2(x') \end{bmatrix} g_0(x,x')dx'\,dx =$$

$$= \frac{1}{\Delta x^2}\frac{df_1(x')}{dx'}\int_{x_1}^{x_2}\int_{x_1}^{x_2} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} g_0(x,x')dx'\,dx +$$

$$+\frac{k^2}{\Delta x^2}\int_{x_1}^{x_2}\int_{x_1}^{x_2} \begin{bmatrix} (x_2-x)(x_2-x') & (x_2-x)(x'-x_1) \\ (x-x_1)(x_2-x') & (x-x_1)(x'-x_1) \end{bmatrix} g_0(x,x')dx'\,dx$$

$$\{V\}_j = -j4\pi\omega\varepsilon \int_{\Delta l_j} E_x^{inc}(x)\begin{bmatrix} f_1(x) \\ f_2(x) \end{bmatrix} dx = -\frac{j4\pi\omega\varepsilon}{\Delta x}\int_{x_1}^{x_2} E_x^{inc}(x)\begin{bmatrix} (x_2-x) \\ (x-x_1) \end{bmatrix} dx$$

where Δl_i, Δl_j assign the widths of *i*-th and *j*-th segments.



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NUMERICAL SOLUTION – Case of free space

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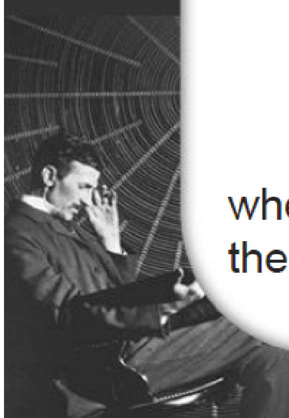
- The evaluation of the right-hand side vector can be undertaken in the closed form if the delta-function voltage generator is used (antenna mode), or the plane wave excitation (scatterer mode).
- In the radiation mode right-side vector is different from zero only in the feed gap area.
- The x-component of the impressed (incident) electric field is given by:

$$E_x^{inc}(x) = \frac{V_g}{\Delta l_g}$$

where V_g is the feed voltage and $\Delta l_g = \Delta x$ (for convenience) is the feed-gap width.



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NUMERICAL SOLUTION – Case of free space

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FESB

$E_x^{inc}(x) = E_0$
$E_x^{inc}(x) = E_0$

- Using the linear shape functions it follows:

$$\{V\}_j = -\frac{j4\pi\omega\varepsilon}{\Delta l_g}\int_{x_1=-\frac{\Delta l_g}{2}}^{x_2=\frac{\Delta l_g}{2}} \frac{V_g}{\Delta l_g}\begin{bmatrix}(x_2-x)\\(x-x_1)\end{bmatrix}dx = -j2\pi\omega\varepsilon V_g\begin{pmatrix}1\\1\end{pmatrix}$$

- If the scattering mode for the simple case of normal incidence is considered it follows:

$$E_x^{inc}(x) = E_0$$

- The right-hand side vector differs from zero on an each segment and the local voltage vector is:

$$\{V\}_j = -\frac{j4\pi\omega\varepsilon}{\Delta x}\int_{x_1}^{x_2} E_0\begin{bmatrix}(x_2-x)\\(x-x_1)\end{bmatrix}dx = -j2\pi\omega\varepsilon E_0\Delta x\begin{pmatrix}1\\1\end{pmatrix}$$

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NUMERICAL SOLUTION – Field evaluation

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- Applying the BEM formalism to integral formulas for the field above a lossy ground :

$$E_x = \frac{1}{j4\pi\omega\varepsilon_0}\sum_{n=1}^{M}\sum_{i=1}^{N_j}\left[-\frac{I_{i+1,n}-I_{i,n}}{\Delta x}\int_{x_{i,n}}^{x_{i+1,n}}\frac{\partial G_{nm}(x,x')}{\partial x'}dx' + k^2\int_{x_{i,n}}^{x_{i+1,n}} G_{nm}(x,x')I_{in}(x')dx'\right];$$

$$m = 1,2,\ldots,M$$

$$E_y = \frac{1}{j4\pi\omega\varepsilon_0}\sum_{n=1}^{M}\sum_{i=1}^{N_j}\frac{I_{i+1,n}-I_{i,n}}{\Delta x}\int_{x_{i,n}}^{x_{i+1,n}}\frac{\partial G_{nm}(x,x')}{\partial y}dx';\quad m = 1,2,\ldots,M$$

$$E_z = \frac{1}{j4\pi\omega\varepsilon_0}\sum_{n=1}^{M}\sum_{i=1}^{N_j}\frac{I_{i+1,n}-I_{i,n}}{\Delta x}\int_{x_{i,n}}^{x_{i+1,n}}\frac{\partial G_{nm}(x,x')}{\partial z}dx';\quad m = 1,2,\ldots,M$$

- N_j is the total number of boundary elements on the j-th wire

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NUMERICAL SOLUTION – Field evaluation

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- Applying the BEM formalism to integral formulas for the field transmitted into a lossy medium :

$$E_x = \frac{1}{j4\pi\omega\varepsilon_{eff}} \sum_{i=1}^{N_j} \left[-\frac{I_{2i}-I_{1i}}{\Delta x_j} \int_{x_{1ij}}^{x_{2i}} \frac{\partial G(x,x',z)}{\partial x'} dx' - \gamma^2 \int_{x_{1ij}}^{x_{2ij}} \left[I_{1i}\frac{x_{2i}-x'}{\Delta x} + I_{2i}\frac{x'-x_{1i}}{\Delta x} \right] G(x,x',z) I(x') dx' \right]$$

- N_j is the total number of boundary elements on the *j*-th wire

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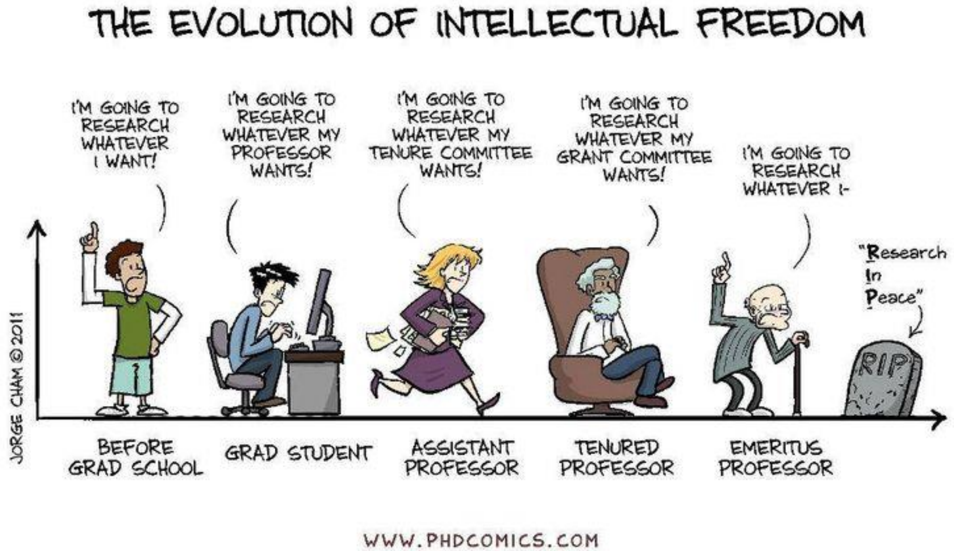
Concluding remarks



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CONCLUDING REMARKS

- Theoretical background of SuZANA and TWiNS codes is presented.
- Formulation is based on the space-frequency integro-Pocklington equation and the corresponding field integrals.
- The influence of the air-ground interface is taken into account via the related reflection/transmission coefficients.
- The Pocklington IDE is solved via the Galerkin-Bubnov variant of the Indirect Boundary Element Method (GB-IBEM) and the corresponding reflected/transmitted fields are evaluated using BEM formalism, as well.

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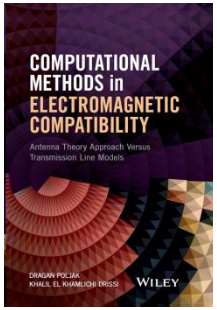
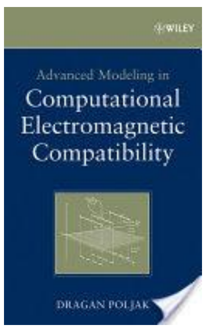
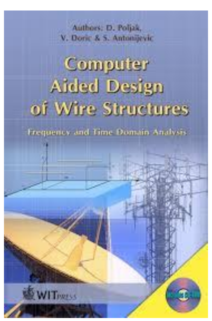
References



[1] D.Poljak, K. El Khamlichi Drissi, *Computational Methods in Electromagnetic Compatibility*, New Jersey: John Wiley & Sons, Inc., 2018.



[2] D. Poljak, *Advanced Modeling in Computational Electromagnetic Compatibility*, New Jersey: John Wiley & Sons, Inc., 2007.



[3] D. Poljak, V. Doric, A. Antonijevic, *Computer Aided Design of Wire Structures, Frequency and Time Domain Analysis, Southampton*, UK, Boston, USA : WIT Press, 2007.

IMPROVED FORMULATION

- Geometry of interest – dipole antenna above a two-layered lossy ground

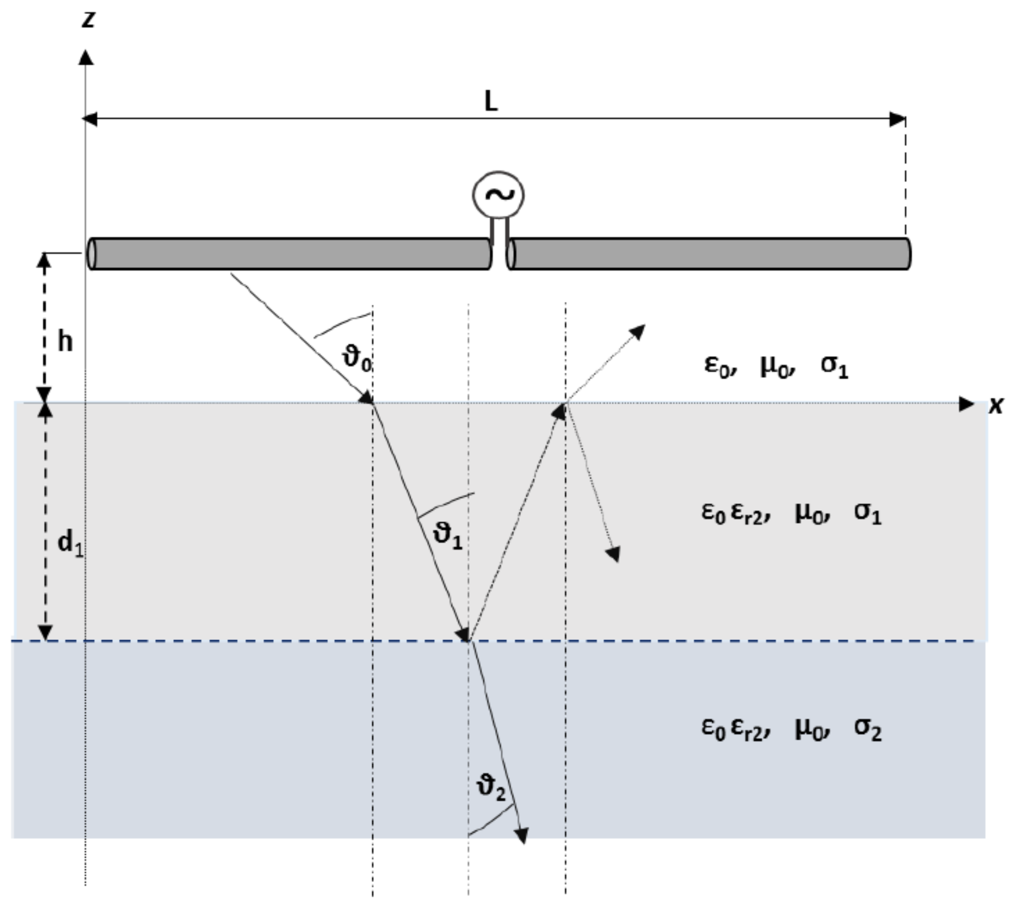


Fig. 1. Dipole antenna located over a two layered lossy half-space

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IMPROVED FORMULATION

- The Pocklington equation and field formulas.

$$E_x^{exc} = j\,\omega \frac{\mu}{4\pi}\int_{-\frac{L}{2}}^{\frac{L}{2}} I(x')g(x,x')dx' - \frac{1}{j4\pi\omega\varepsilon_0}\frac{\partial}{\partial x}\int_{-\frac{L}{2}}^{\frac{L}{2}} \frac{\partial I(x')}{\partial x'} g(x,x')dx'$$

$$g(x,x') = g_0(x,x') - R_{TM}\, g_i(x,x')$$

$$g_0(x,x') = \frac{e^{-jk_0R_0}}{R_0}, \quad g_i(x,x') = \frac{e^{-jk_0R_i}}{R_i}$$

$$E_x = \frac{1}{j4\pi\omega\varepsilon_0}\left[\int_0^L \frac{\partial I(x')}{\partial x'}\frac{\partial g(x,y,z,x')}{\partial x}dx' - \gamma^2\int_0^L I(x')g(x,x')dx'\right]$$

$$E_y = \frac{1}{j4\pi\omega\varepsilon_0}\int_0^L \frac{\partial I(x')}{\partial x'}\frac{\partial g(x,y,z,x')}{\partial y}dx'$$

$$E_z = \frac{1}{j4\pi\omega\varepsilon_0}\int_0^L \frac{\partial I(x')}{\partial x'}\frac{\partial g(x,y,z,x')}{\partial z}dx'$$

$$g(x,x') = T_{TM}\, g_0(x,x')$$

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IMPROVED FORMULATION

- Corresponding field expressions, reflection/transmission coefficients…

$$E_0^+ = \frac{1}{\tau_{01}} E_1^+ + \frac{\rho_{01}}{\tau_{01}} E_1^-$$

$$E_0^- = \frac{\rho_{01}}{\tau_{01}} E_1^+ + \frac{1}{\tau_{01}} E_1^-$$

$$E_1^+ = \frac{1}{\tau_{12}} e^{\gamma_1 \cos\vartheta_1 d_1} E_2^+$$

$$E_1^- = \frac{\rho_{12}}{\tau_{12}} e^{-\gamma_1 \cos\vartheta_1 d_1} E_2^+$$

$$\rho_{mn} = \frac{Z_n \cos\vartheta_n - Z_m \cos\vartheta_m}{Z_n \cos\vartheta_n + Z_m \cos\vartheta_m} \quad m = 0,1$$

$$\tau_{mn} = \frac{2Z_n \cos\vartheta_m}{Z_n \cos\vartheta_n + Z_m \cos\vartheta_m} \quad n = 1,2$$

$$M_{mn} = \frac{1}{\tau_{mn}} \begin{bmatrix} 1 & \rho_{mn} \\ \rho_{mn} & 1 \end{bmatrix} \quad m = 0,1, n = 1,2$$

$$Z_k = \sqrt{\frac{j\omega\mu_0}{\sigma_k + j\omega\varepsilon_0\varepsilon_{rk}}} \quad k = 0,1,2$$

$$P_{12} = \begin{bmatrix} e^{\gamma_1 \cos\vartheta_1 d_1} & 0 \\ 0 & e^{-\gamma_1 \cos\vartheta_1 d_1} \end{bmatrix}$$

$$\gamma_k = \sqrt{j\omega\mu_0(\sigma_k + j\omega\varepsilon_0\varepsilon_{rk})} \quad k = 0,1,2$$

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IMPROVED FORMULATION

- Corresponding field expressions, reflection/transmission coefficients…

$$\begin{bmatrix} E_0^+ \\ E_0^- \end{bmatrix} = M_{01} \begin{bmatrix} E_1^+ \\ E_1^- \end{bmatrix}$$

$$\begin{bmatrix} E_1^+ \\ E_1^- \end{bmatrix} = P_{12} M_{12} \begin{bmatrix} E_2^+ \\ E_2^- \end{bmatrix}$$

$$\rho_{mn}^{MIT} = \frac{(Z_m^2 - Z_n^2)}{(Z_m^2 + Z_n^2)} \quad m = 0,1$$

$$\tau_{mn} = \frac{2Z_m^2}{(Z_m^2 + Z_n^2)} \quad n = 1,2$$

$$\vec{E}_0 = E_1^+ (\cos\vartheta_0\, \vec{e}_x + \sin\vartheta_0\, \vec{e}_z) e^{-\gamma_0 (x\sin\vartheta_0 - z\cos\vartheta_0)} + E_0^- (\cos\vartheta_0\, \vec{e}_x - \sin\vartheta_0\, \vec{e}_z) e^{-\gamma_0 (x\sin\vartheta_0 + z\cos\vartheta_0)}$$

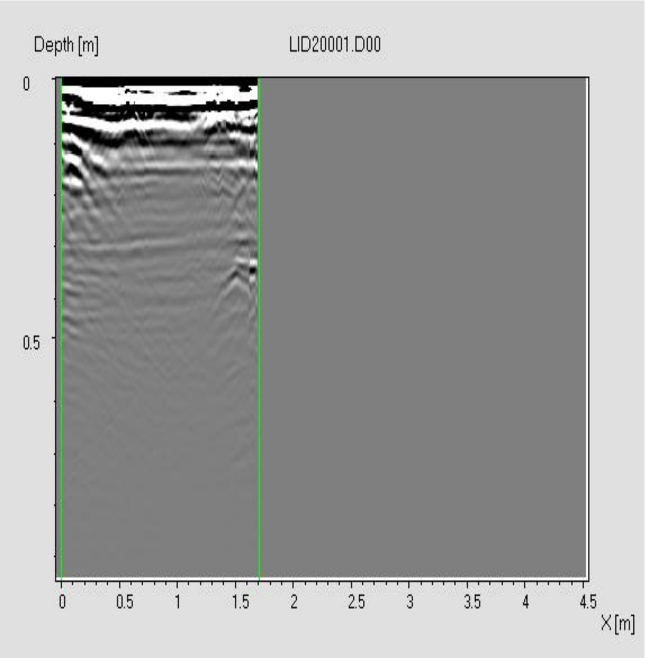
$$\vec{E}_1 = E_1^+ (\cos\vartheta_1\, \vec{e}_x + \sin\vartheta_1\, \vec{e}_z) e^{-\gamma_1 (x\sin\vartheta_1 - z\cos\vartheta_1)} + E_1^- (\cos\vartheta_1\, \vec{e}_x - \sin\vartheta_1\, \vec{e}_z) e^{-\gamma_1 (x\sin\vartheta_1 + z\cos\vartheta_1)}$$

$$\vec{E}_2 = E_2^+ (\cos\vartheta_2\, \vec{e}_x + \sin\vartheta_2\, \vec{e}_z) e^{-\gamma_2 (x\sin\vartheta_2 - z\cos\vartheta_2)}$$

- Faculty of Civil Engineering, University of Osijek

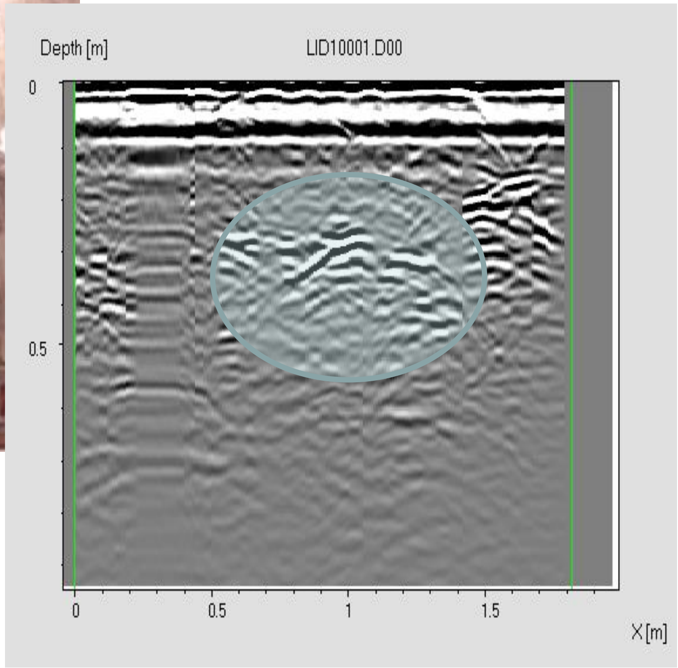
- Faculty of Civil Engineering, architecture and Geodesy, UnIversity of Split


GRAĐEVINSKI FAKULTET OSIJEK
Faculty of Civil Engineering Osijek



Suspected secret passage in the basement of the medieval house in Osijek, Croatia.
The passage was not found.
Roman tombstone was probably used as a part of home shrine.
900 MHz IDS antenna was used

This research is a joint effort of **Faculty of Civil Engineering Osijek** and **Faculty of Civil Engineering, Architecture and Geodesy in Split.**



15th century monastery on the island Badija, Croatia. GPR survey was performed in order to determine the structural integrity and composition of the walls.
2 GHz bipolar IDS antenna was used.

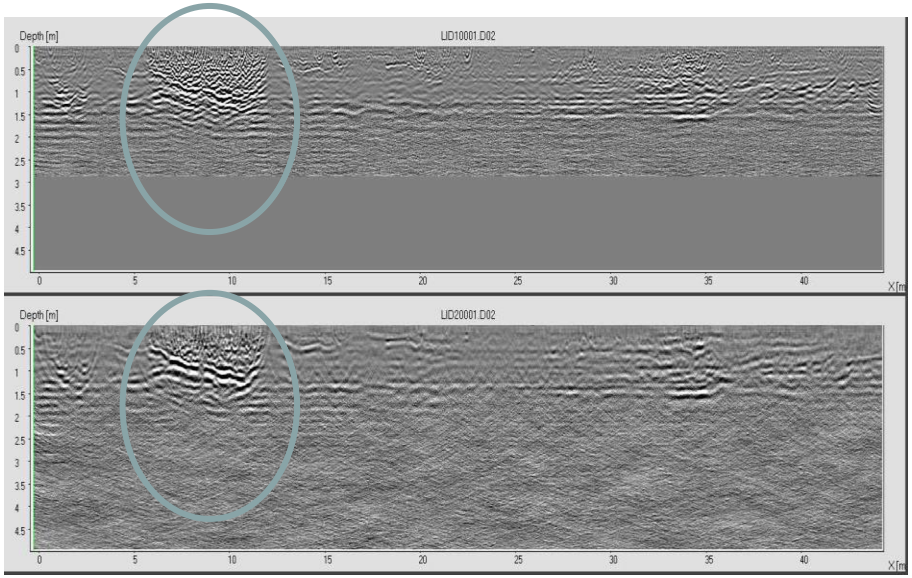
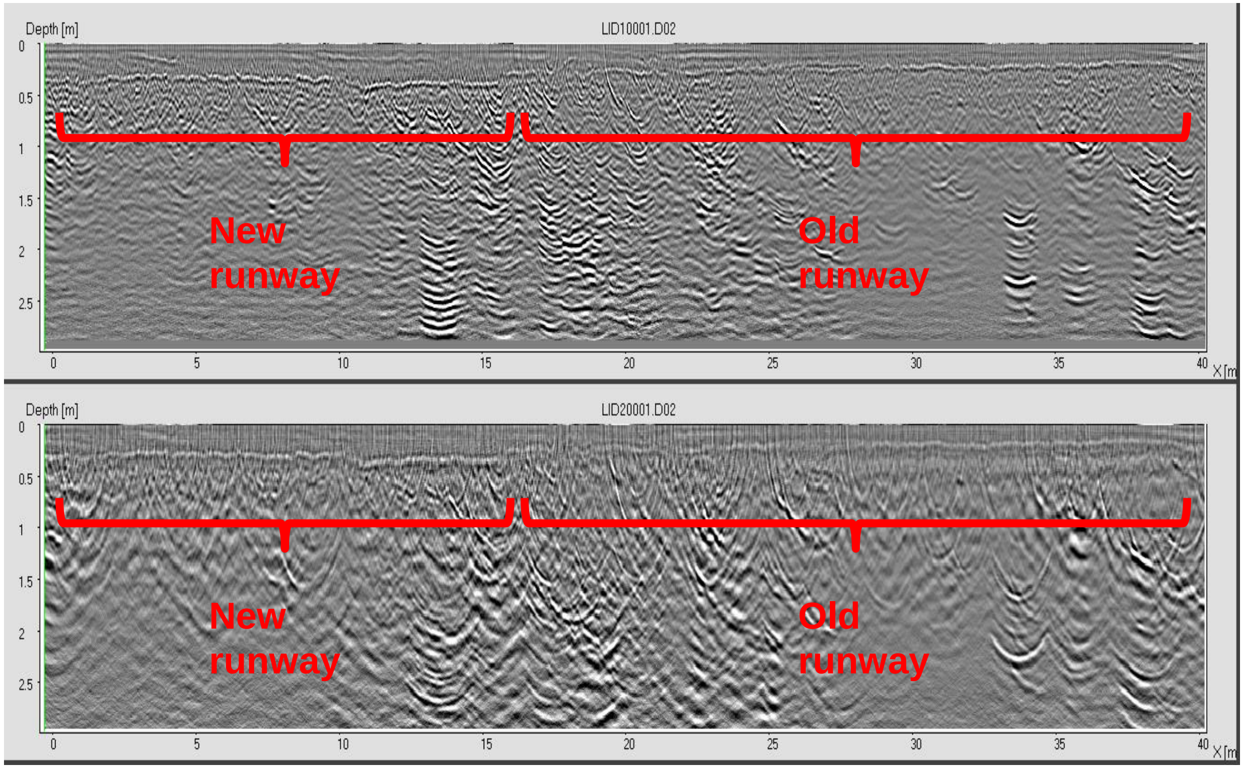


Photo by B. Nadilo & Z. Tanocki

13th century castle Korodj, near Osijek, Croatia. The archaeologists hypothesized that waterway which connected small river and moat (inner water trench) existed. Probable location was found.
Dual 200/600 MHz IDS antenna was used.

Photo by Josip Sočo



GPS survey of the Brač airport runway (island Brač, Croatia), testing new runway.
Dual 200/600 MHz IDS antenna was used.

This survey is a joint effort of **Faculty of Civil Engineering Osijek** and **Faculty of Civil Engineering, architecture and Geodesy in Split.**

- Faculty of Civil Engineering, University of Zagreb

University of Zagreb

Faculty of Civil Engineering

Department of Transportation

Training school - Roma

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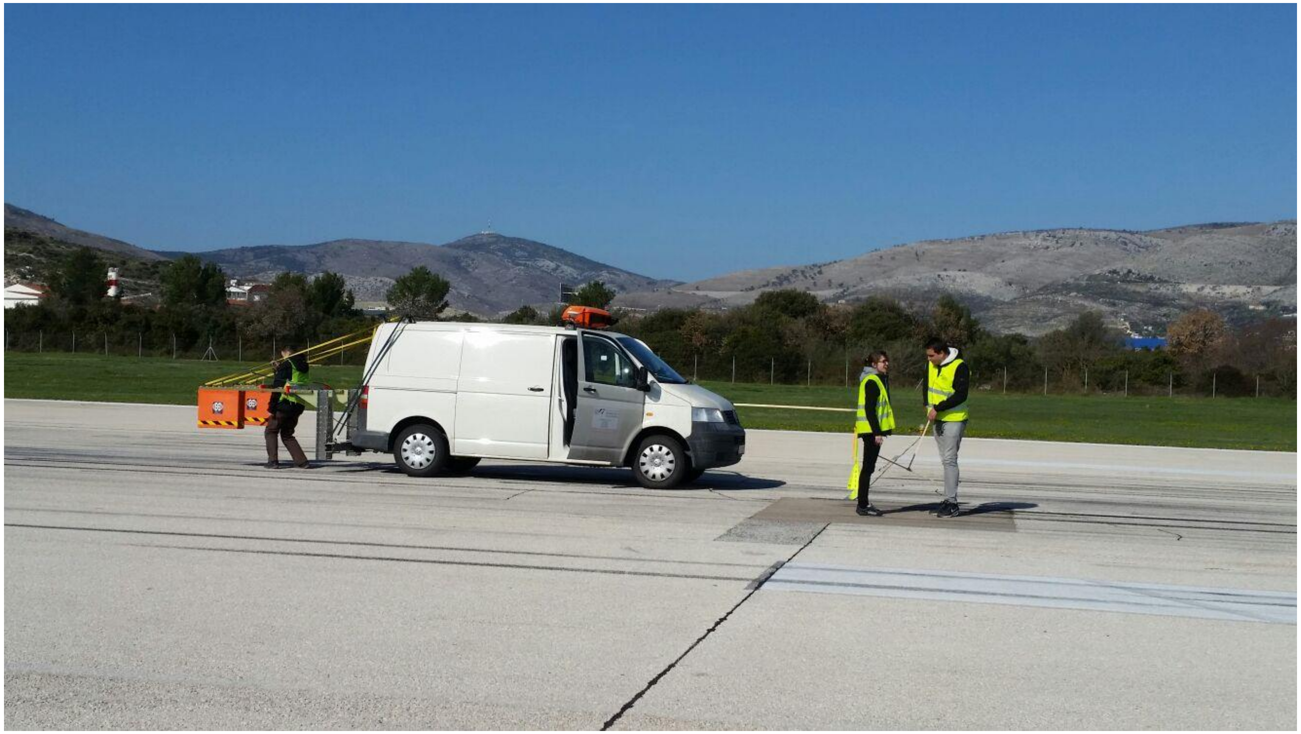
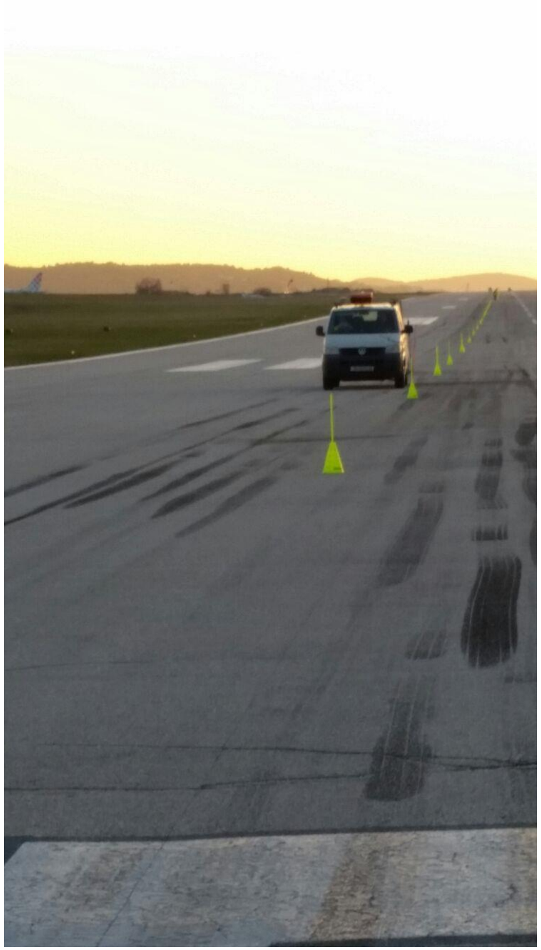
Faculty of Civil Engineering

EST.	01.10.1919
ACADEMIC STAFF	192
STUDENTS	cca 1500
DEPARTMENTS	9
LABORATORIES	4

Split Airport





preparing for measurement on Split Airport

measuring at the end of the day

- the central part of the runway was divided into 15 sections, for which 16 lines of measurement are defined
- the driving of the vehicle on the define lines was ensured by setting the plastic cone every 25 to 30 m

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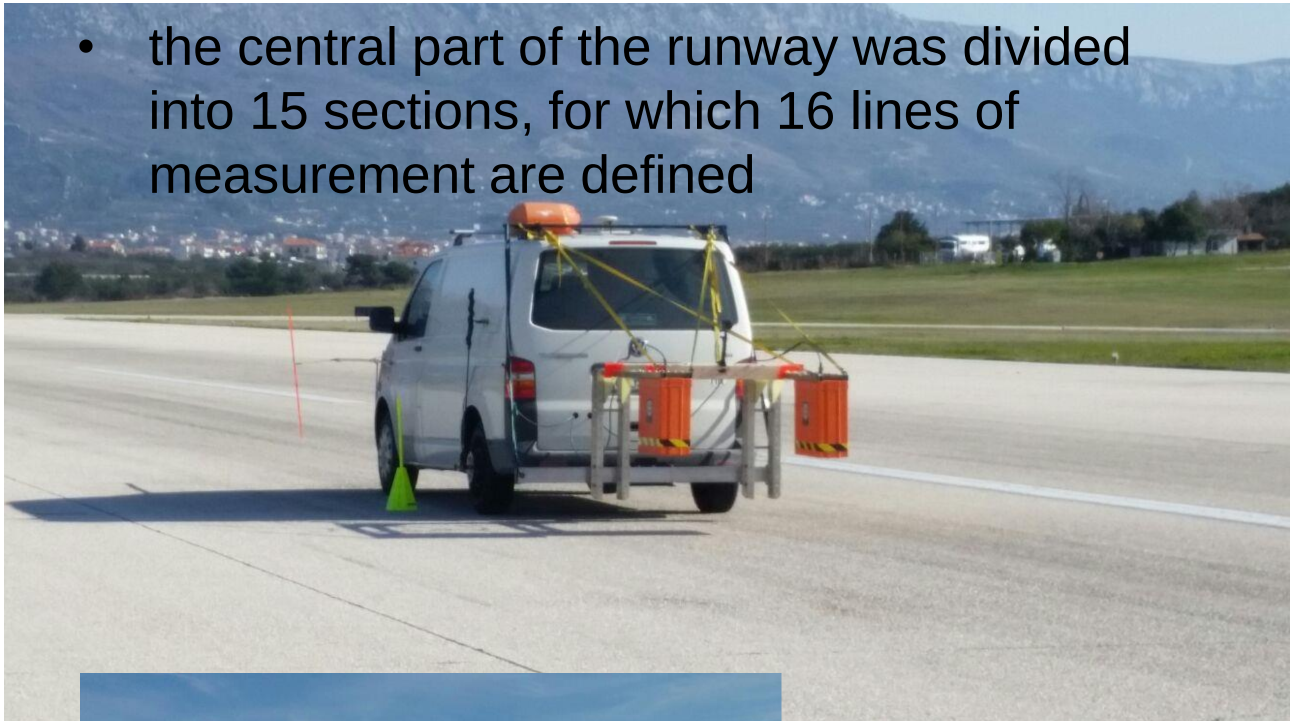
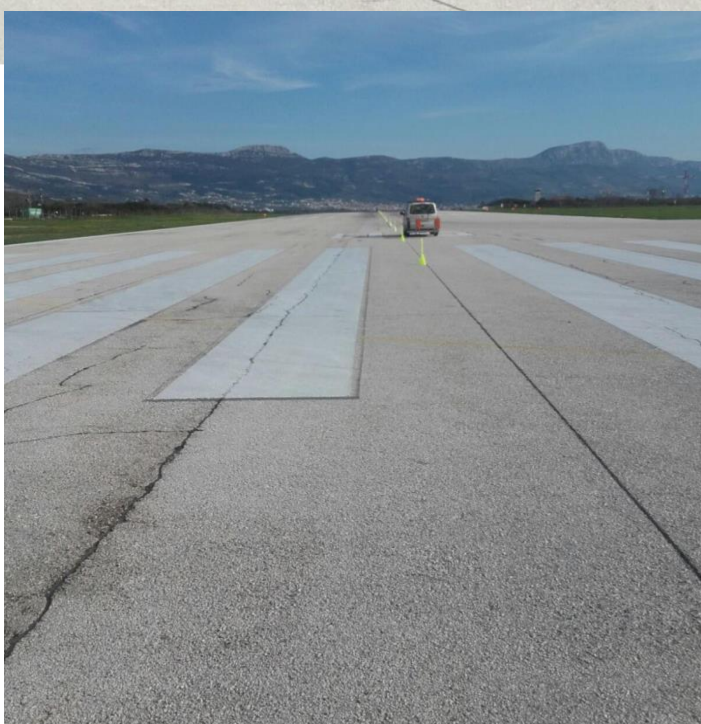
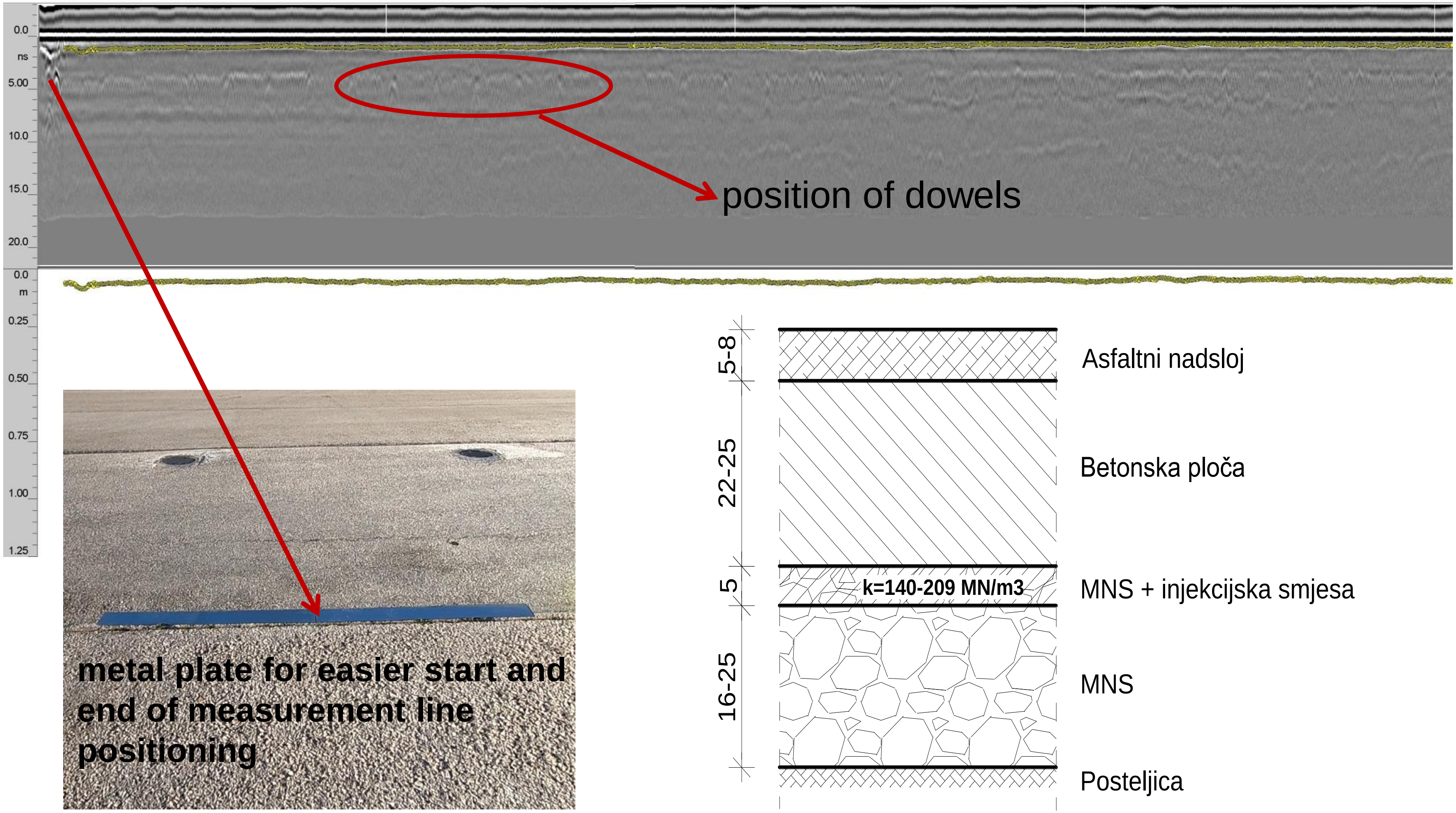


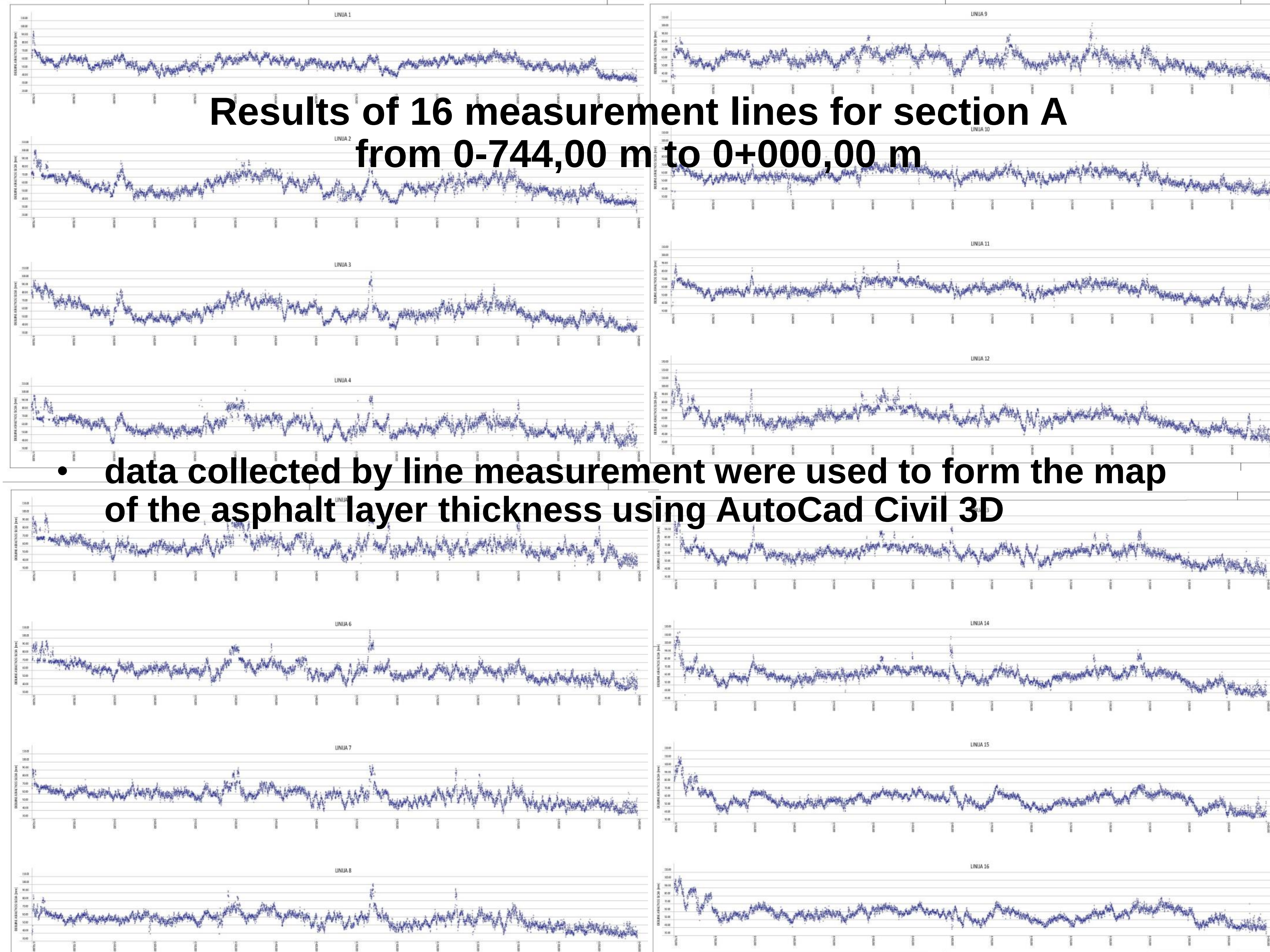


- the driving of the vehicle on the define lines was ensured by setting the plastic cone every 25 to 30 m

Radargram, one measurement line on section A

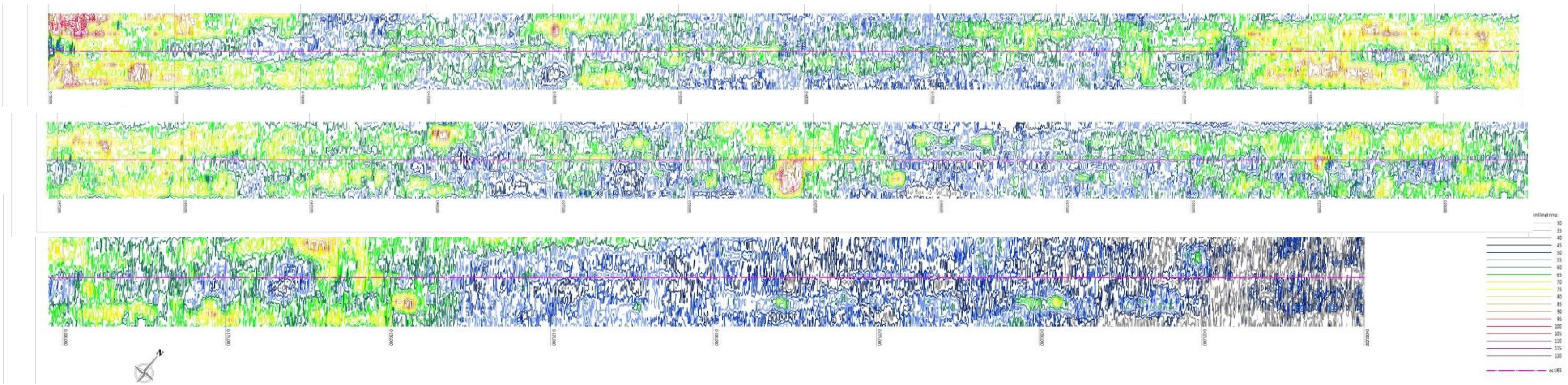


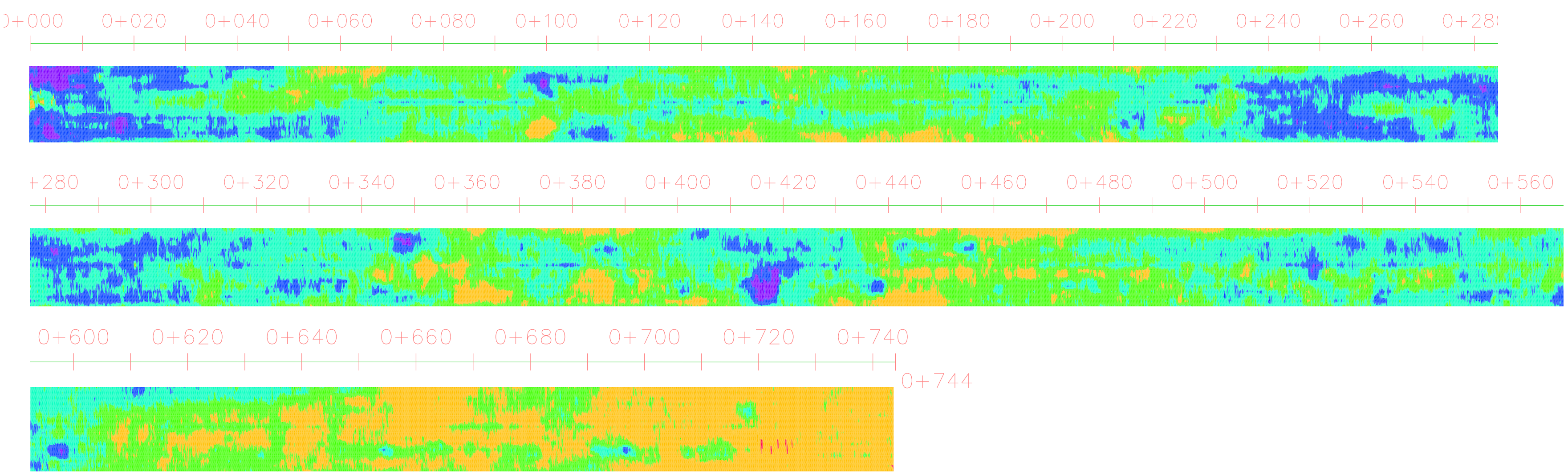
Results of 16 measurement lines for section A from 0-744,00 m to 0+000,00 m



- **data collected by line measurement were used to form the map of the asphalt layer thickness using AutoCad Civil 3D**

Asphalt thicknesses map for section A from 0-744,00 m to 0+000,00 m





- **asphalt layer thicknesses map have been used to determine the depth of milling and to help designer to find optimal solution for pavement rehabilitation**

Department of Transportation
Faculty of CE, University of Zagreb
Fra Andrije Kačića Miošića 26,
10 000 Zagreb, Croatia

Josipa Domitrović
+385 1 4639 241
jdomitrovic@grad.hr

prof. Tatjana Rukavina
Head Professor of Chair for Roads
+385 1 4639 327
rukavina@grad.hr

Authors

Anna Šušnjara received the B.S. and M.S. degrees from FESB University of Split, Croatia, in 2012 and 2014, respectively, where she is currently pursuing the Ph.D. degree. Her current research interests include the stochastic algorithms for uncertainty quantification and sensitivity analysis in CEM and bioelectromagnetism. She received the Best Poster Award at BioEM Conference, Ghent, in 2016. She is a member of the FESB's Research Group on a project EUROfusion Work Package—Code Development for Integrated Tokamak Modeling since 2015

Dragan Poljak is the Full Professor at University of Split, FESB. His research interests include frequency and time domain computational methods in electromagnetics, particularly in the numerical modelling of wire antennas, human exposure of electromagnetic fields and magnetohydrodynamics. Professor Poljak is a senior member of IEEE, a member of the Editorial Board of the journal Engineering Analysis with Boundary Elements, and co-chairman of many WIT International Conferences. In June 2004, professor Poljak was awarded by the National Prize for Science.

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Thank you very much for your attention!

"After solving the towns equation, the stranger rode off, into the setting sun."

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