



Georadar – Ground Penetrating Radar

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Uvod



Introduction

Radar (RAdio Detection And Ranging) is technology developed for detection mostly aerial or above-ground objects.

The idea is simple: transmit the electromagnetic energy (a pulse), and detect a small amount of that energy reflected from the target.

The time delay of the reflection contains information on the range of the target.

Introduction

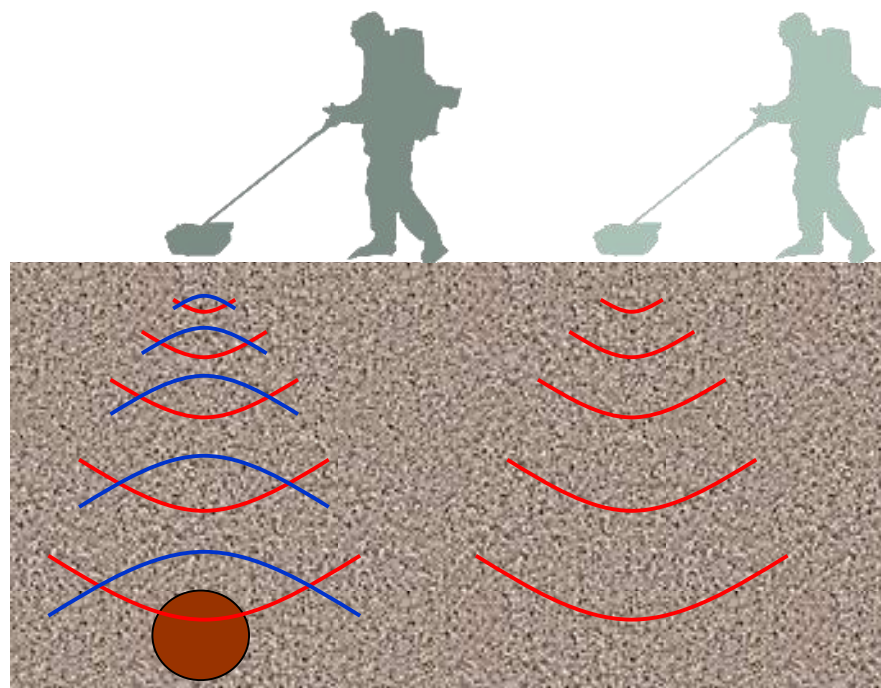
First patent by Leimbach and Lowy in 1910 (Germany) used EM signals to detect buried objects.

Further development encouraged by mining companies in 1930s and from 1970s first commercial equipment.

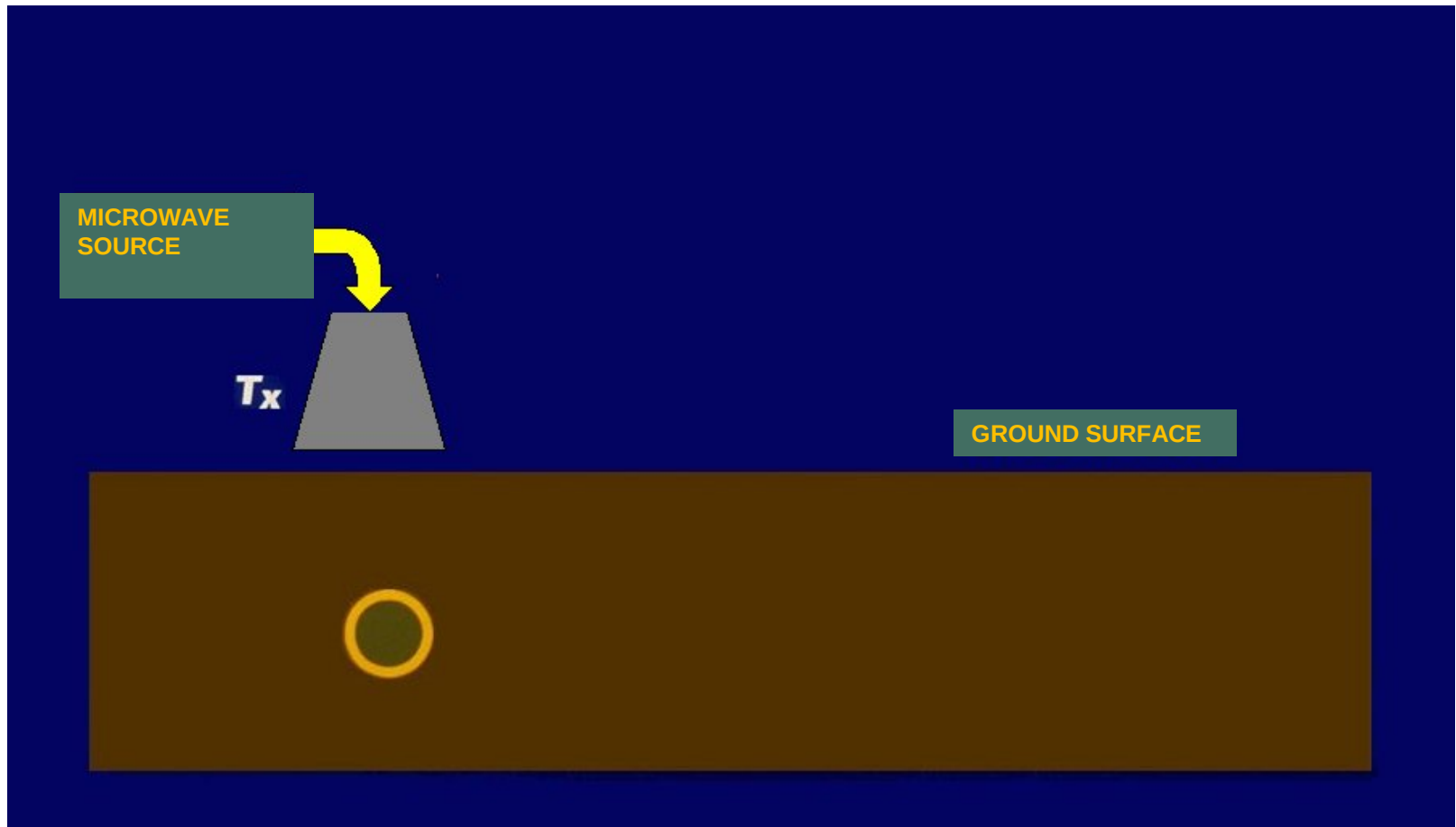
Today, Ground Penetrating Radar is used in many applications: road condition survey, archaeology, geophysics, structural engineering, forensics...

Principles

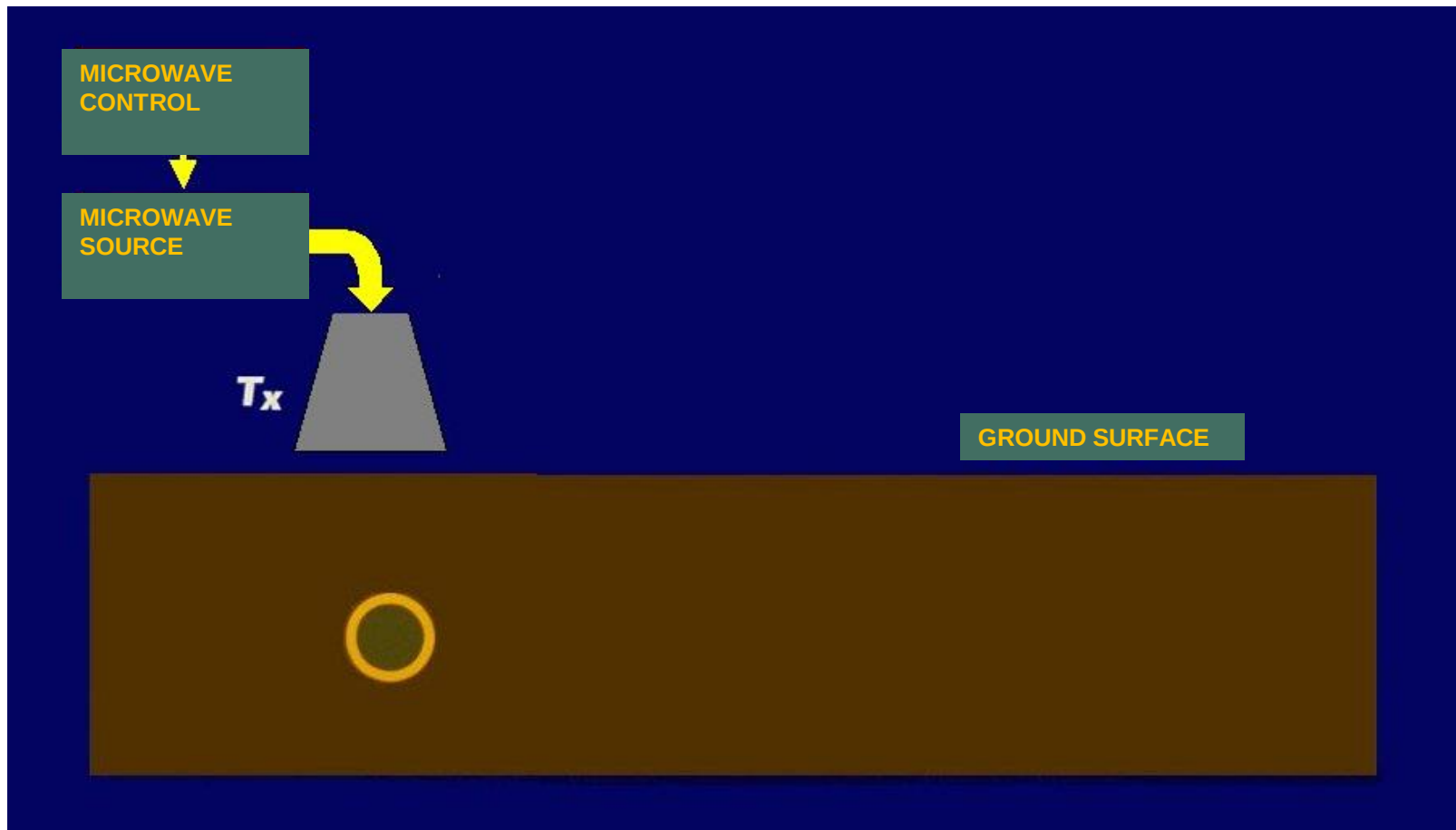
- The Georadar transmits a very short pulse of EM energy into the material by a transmitting antenna
- Energy reflected by discontinuities is captured by a receiving antenna
- Depth range & resolution are related to the radar frequency, transmitted power, host material EM properties and to the shape and characteristics of the targets



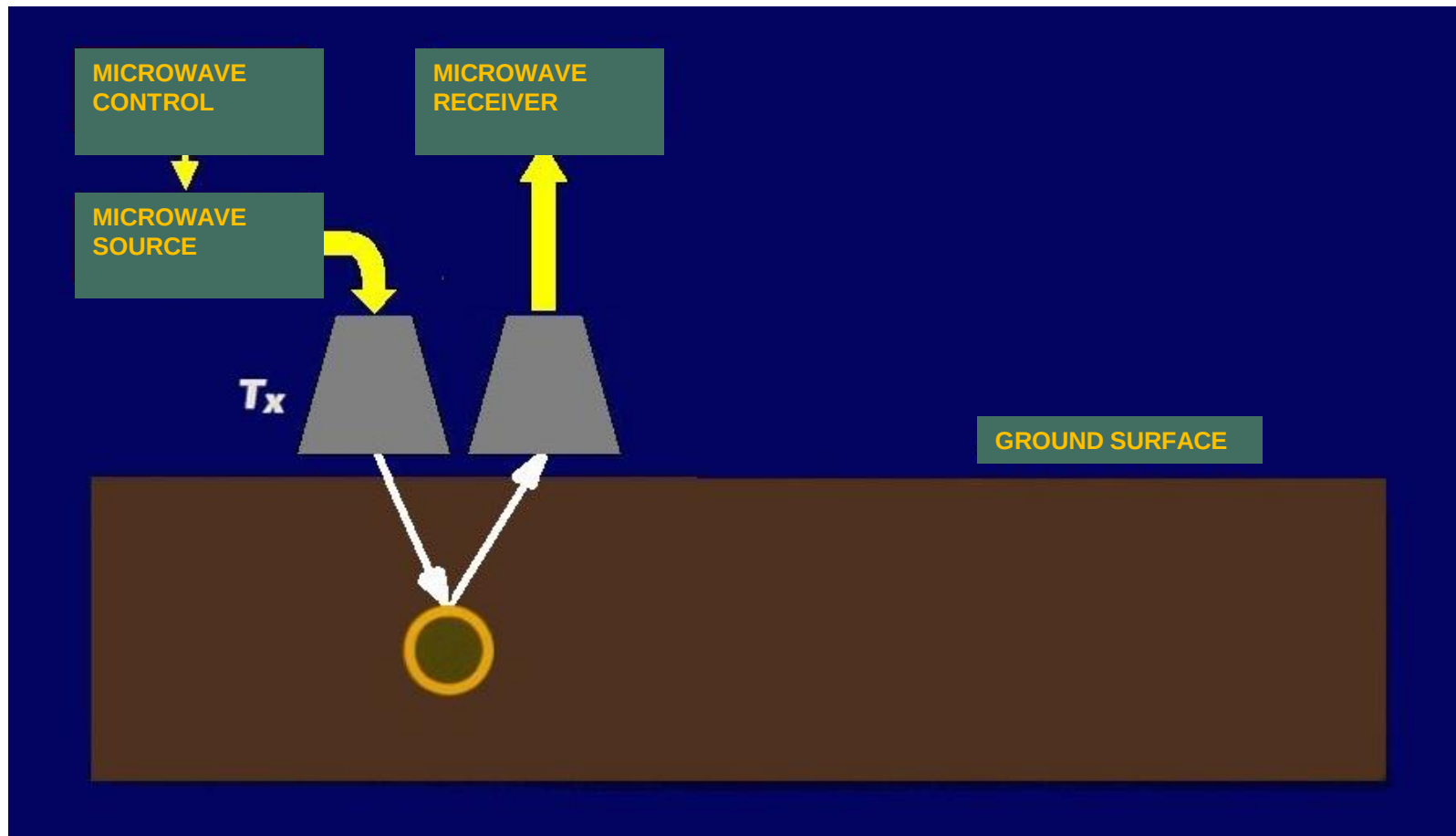
Principles



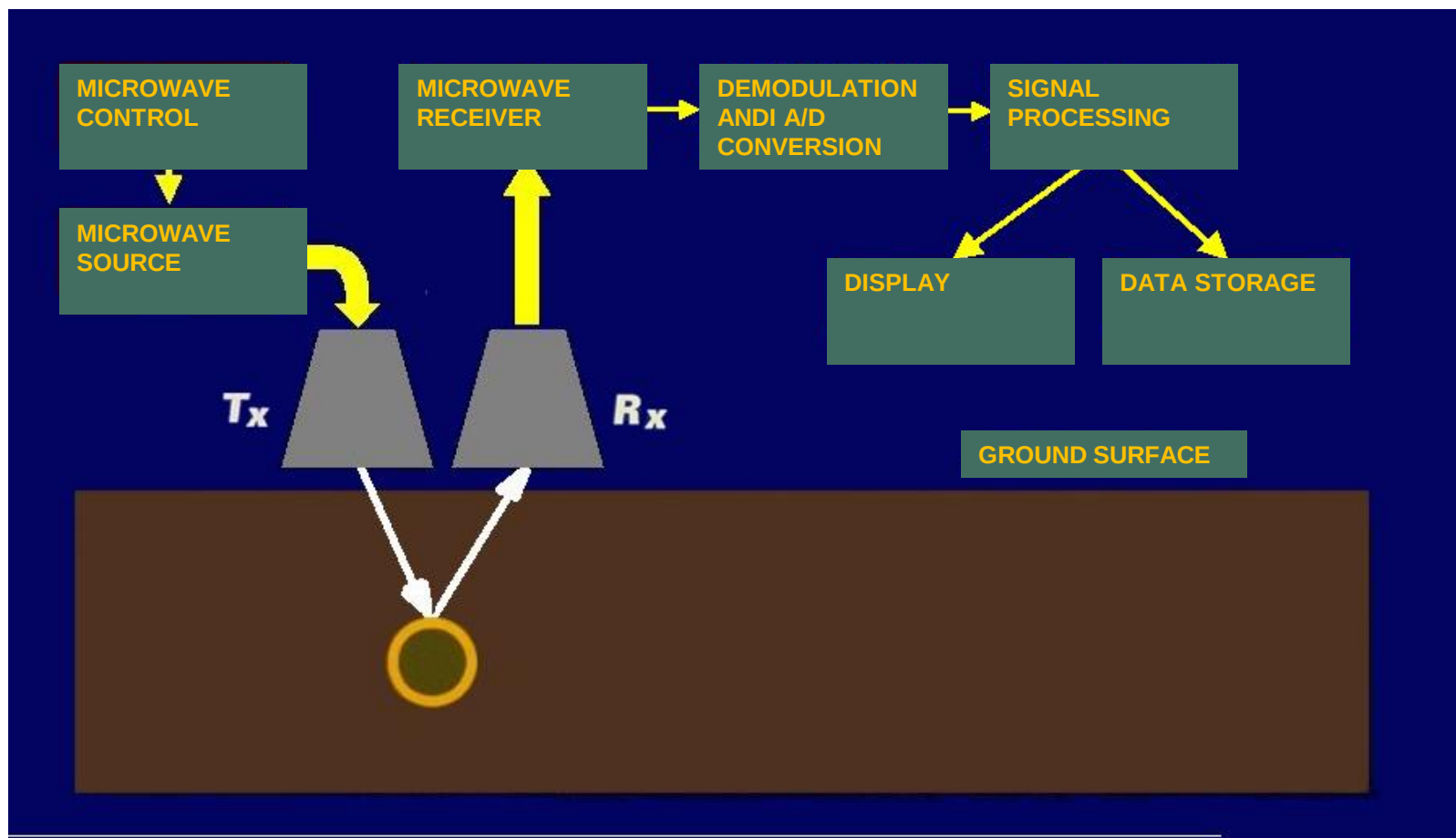
Principles



Principles



Principles



Equipment

Control unit



- Generation of transmitting and receiving signals
- A/D conversion of the signals
- Data storage and visualization

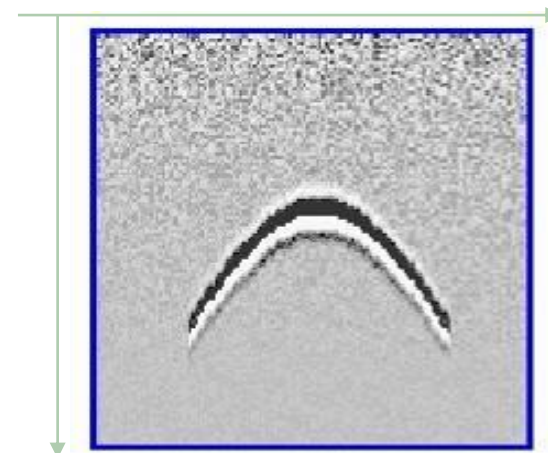
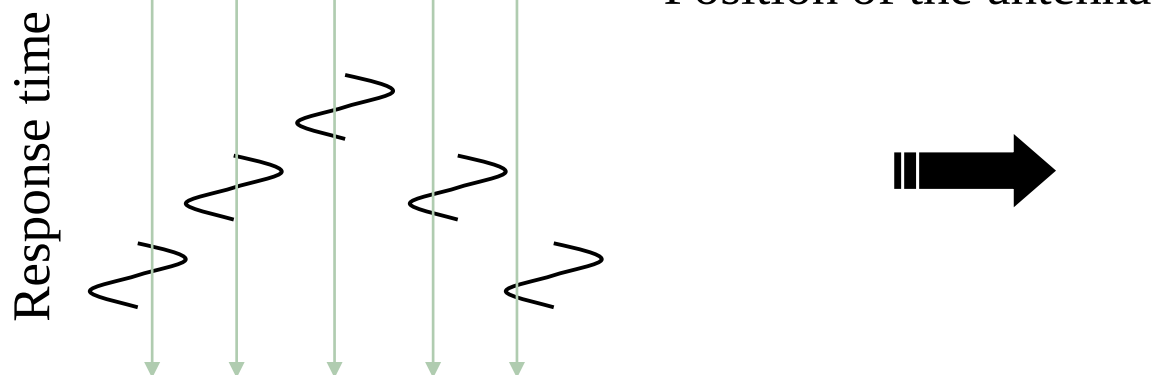
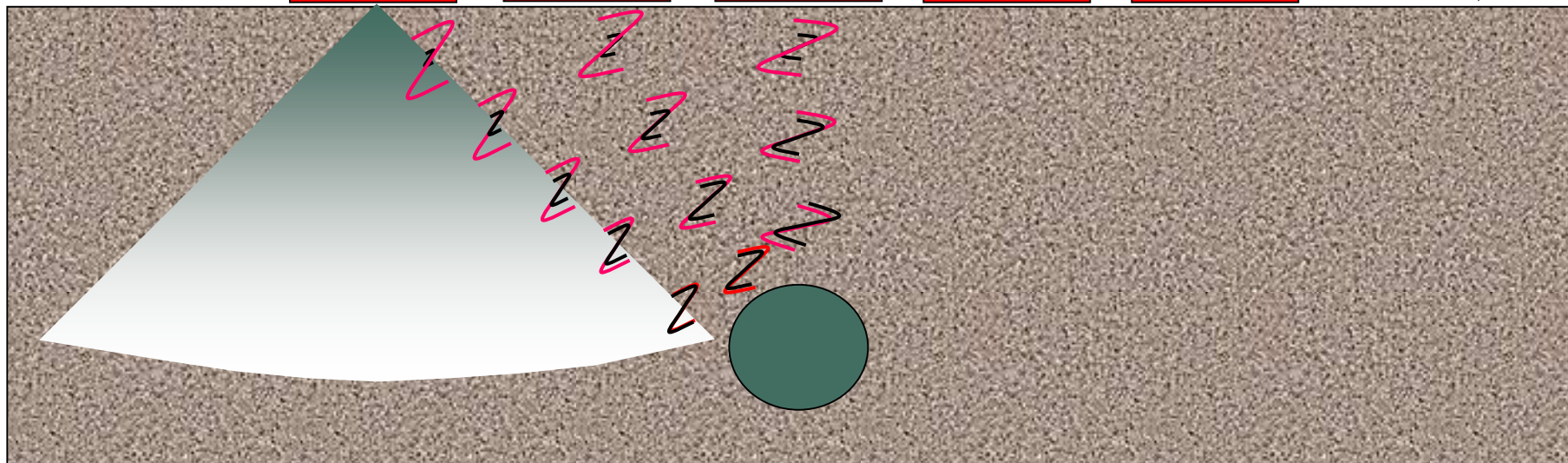
Equipment

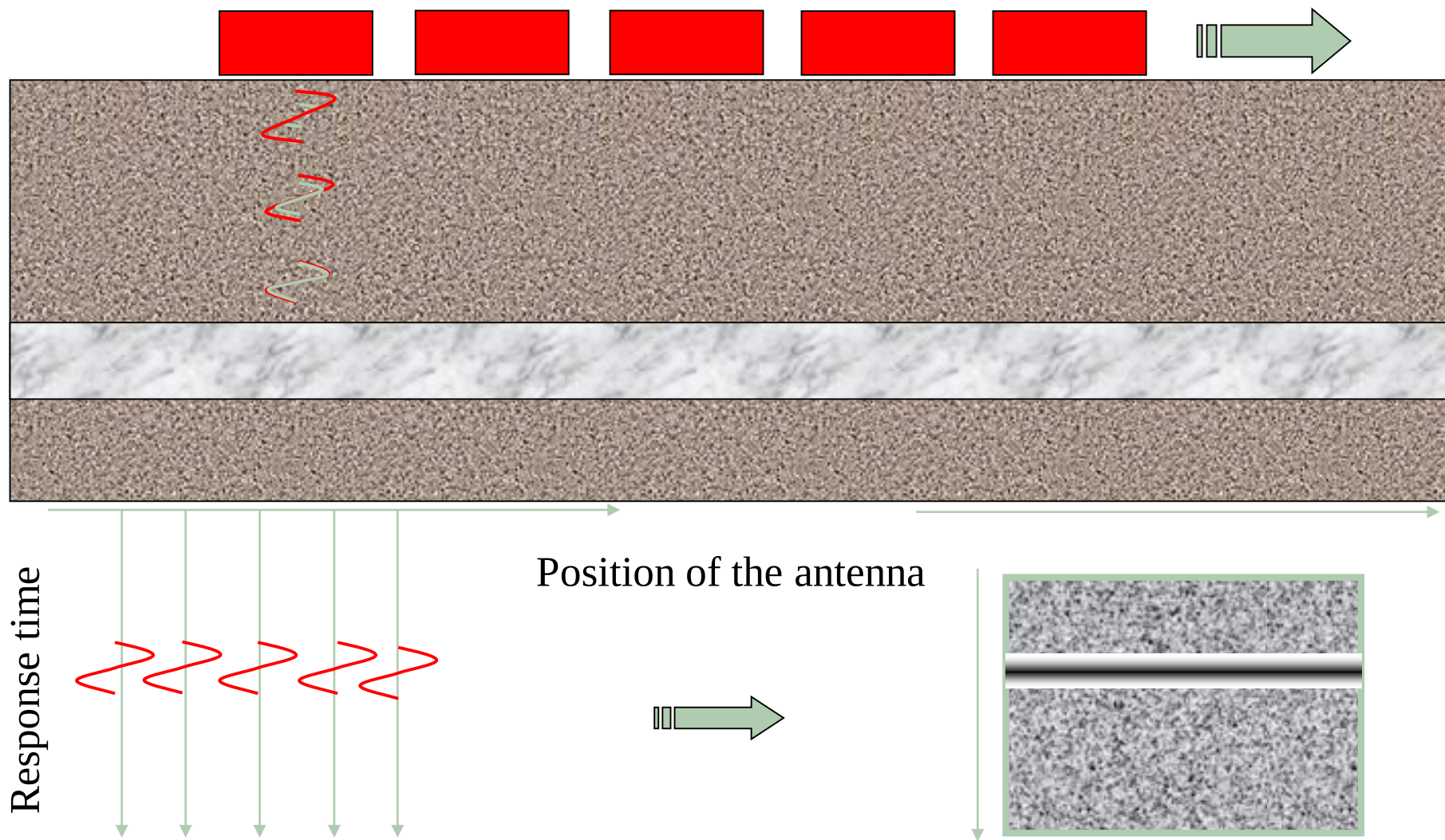


Equipment



Antenna





Key questions

How deep I can see?

What is the accuracy?

What is the minimum target size?

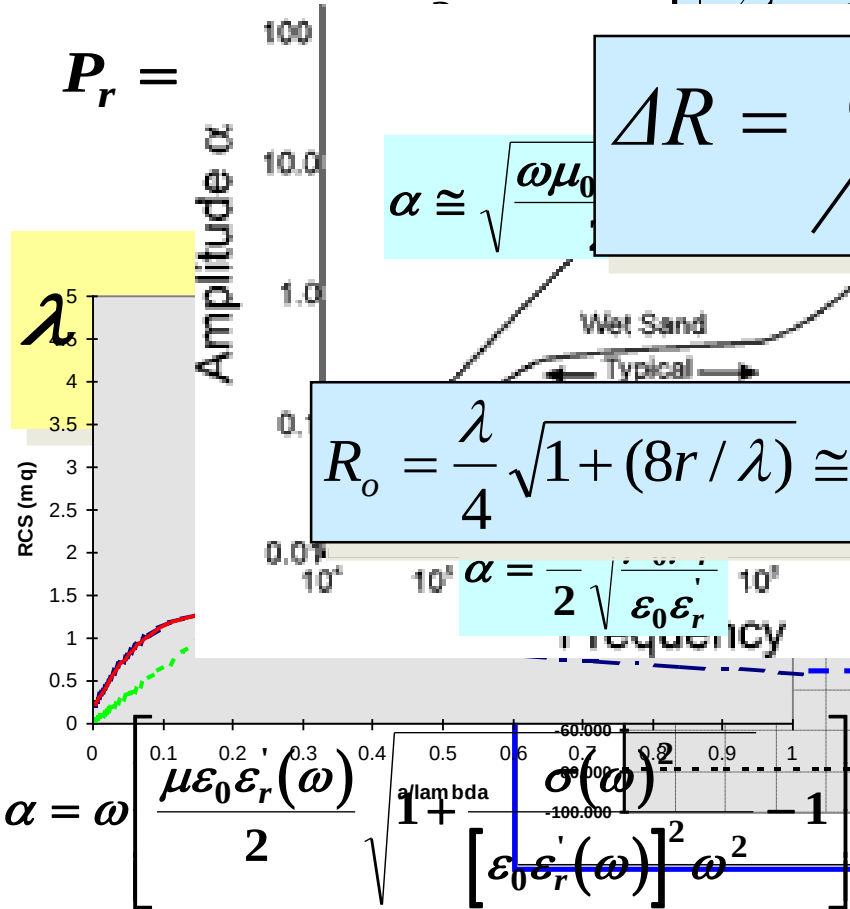
What horizontal and vertical resolution I can expect?

	Meaning	RCS
$a/\lambda \ll \frac{1}{2}$	"small" line reflector (wire)	π^2

$$\Delta R = \frac{c}{2B\sqrt{\mu_r \epsilon_r}}$$

$$\alpha \approx \sqrt{\frac{\omega \mu_0}{2}}$$

$$R_o = \frac{\lambda}{4} \sqrt{1 + (8r/\lambda)} \approx \sqrt{r\lambda/2}, \text{ assuming that } r \gg \lambda$$



ϵ'_r	σ	α (dB/m)
2.6	1.40E-04	0.14
25	6.90E-03	2.26
2.5	1.10E-04	0.11
19	2.10E-02	7.89
2.4	2.70E-04	0.29
7	1.00E-01	61.86
6	4.00E-02	26.73
8	2.50E-02	14.47

A little bit simpler...

Quality of the survey depends on electrical conductivity of the material:

- Low conductivity – excellent radar conditions
air, dry granite, dry limestone, concrete, asphalt
- Medium conductivity – medium radar conditions
freshwater, seawater and freshwater ice, snow, sand, silt, dry clay, basalt
- High conductivity - poor radar conditions
wet clay, wet shale, seawater

A little bit simpler...

The range depth

- DECREASES when: electrical conductivity increases, water content increases, clay content increases, scattering increases, conductive contaminant increases

**User has no control over the above factors
these are site specific characteristics!**

- INCREASES when: antenna frequency decreases, receiver sensitivity increases, transmitter power increases

User has, to some degree, control over the above factors!

A little bit simpler...

Recommended antenna frequencies in relation to the depth of the target:

Depth	Frequency
0 - 0.5 m	1000 MHz
0 - 1 m	900 MHz
0 - 2.5 m	500 MHz
0 - 9 m	300 MHz
0 - 20 m	MLF (80, 40, 32, 20, 16 MHz)
0 - >20 m	MLF (80, 40, 32, 20, 16 MHz)

A little bit simpler...

Accuracy of the location:

Horizontal accuracy: depends on the depth of the target but generally a few centimeters can be achieved.

Vertical accuracy: it is based on the time of flight of the signal (double time: back and forth, from antenna to target and back to receiver). So accuracy depends on accurate evaluation of the EM propagation velocity in the medium.

A little bit simpler...

Propagation velocities:

Medium	ϵ_r	v (cm/nsec)
<i>Air</i>	<i>1</i>	<i>30</i>
<i>Water</i>	<i>81</i>	<i>3</i>
<i>Sand</i>	<i>2.6 - 25</i>	<i>19 - 6</i>
<i>Silt</i>	<i>2.5 - 19</i>	<i>19 - 7</i>
<i>Clay</i>	<i>2.4 - 15</i>	<i>19 - 8</i>
<i>Wet basalt</i>	<i>8</i>	<i>11</i>
<i>Wet granite</i>	<i>7</i>	<i>11</i>
<i>Wet shale</i>	<i>6</i>	<i>12</i>
<i>wet limestone</i>	<i>8</i>	<i>11</i>

$$v = \frac{c}{\sqrt{\epsilon_r}}$$

$$v = 10^8 \text{ m / s}$$

A little bit simpler...

But, most of the materials are composed from different layers with different propagation velocities. Basically, it means that calibration is needed.

A little bit simpler...

The smallest target size which may be discovered depends on the ratio (size of the target)/(wavelength of the EM wave), but also on material of the medium and of the target. Generally, minimal ratio for metallic targets in the ground is 0.1, which gives:

Antenna 200MHz



5cm

Antenna 400MHz



2.5cm

Antenna 600MHz



1.25cm

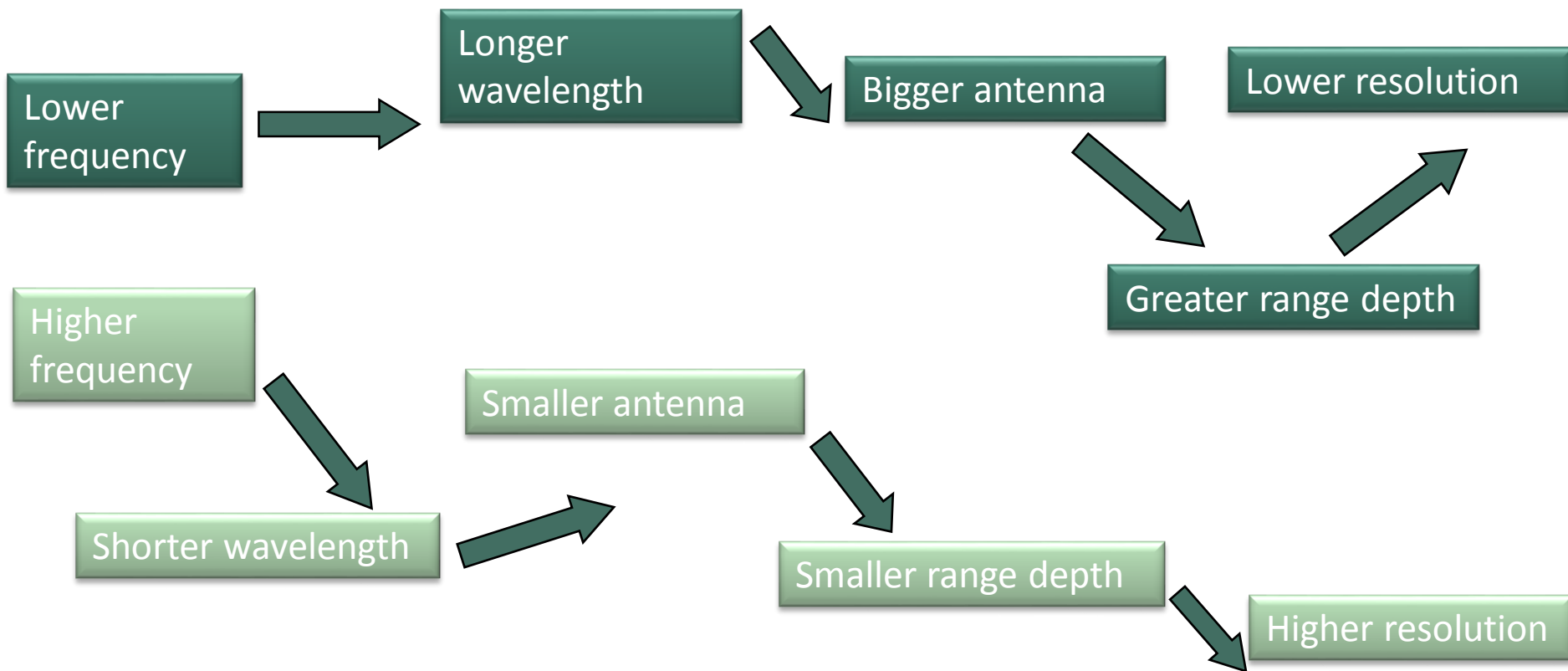
A little bit simpler...

Plan resolution is the capability of the radar system to distinguish close targets at the same depth.

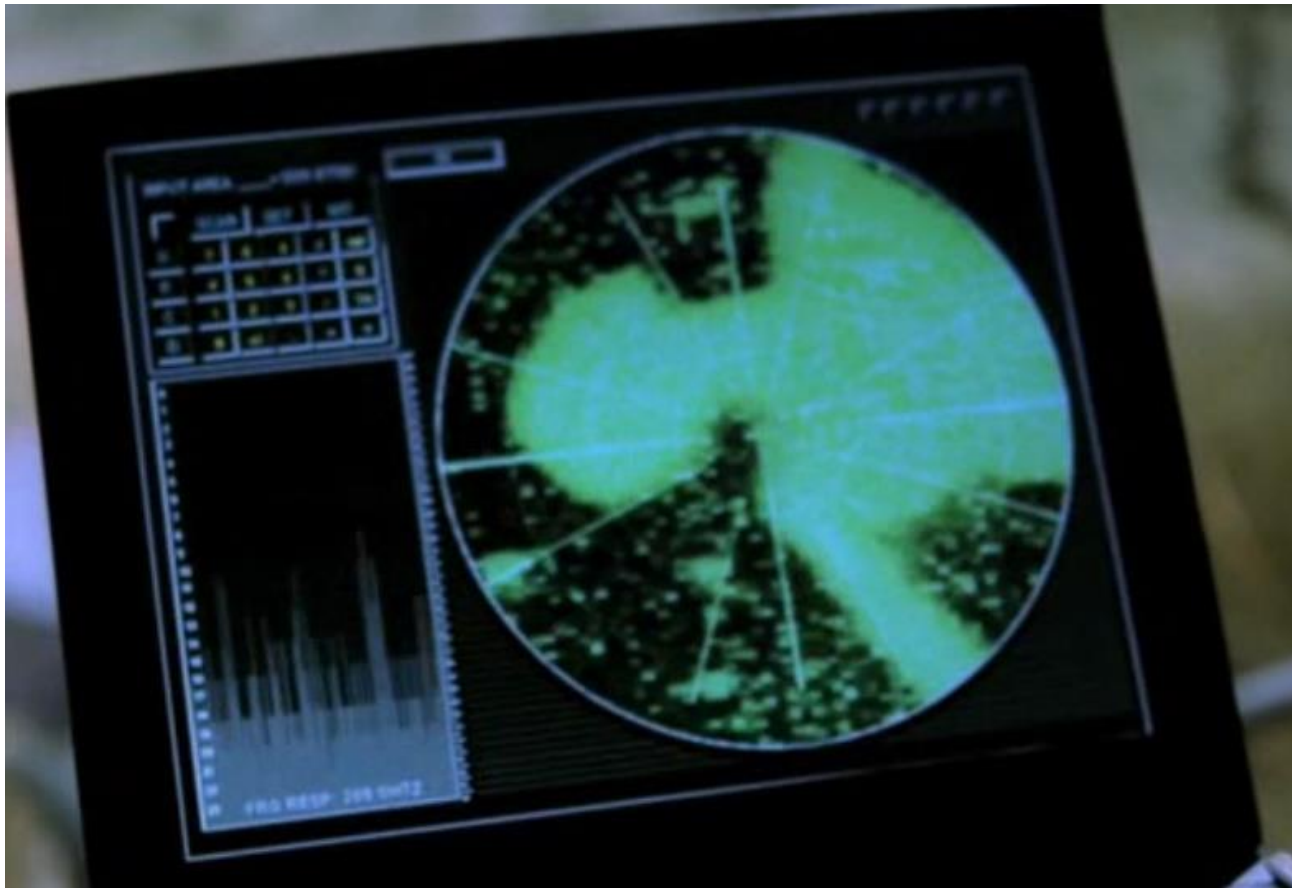
Depth resolution is the capability of the radar system to distinguish various targets in a range.

Generally, higher frequency gives better resolution, both plan and depth.

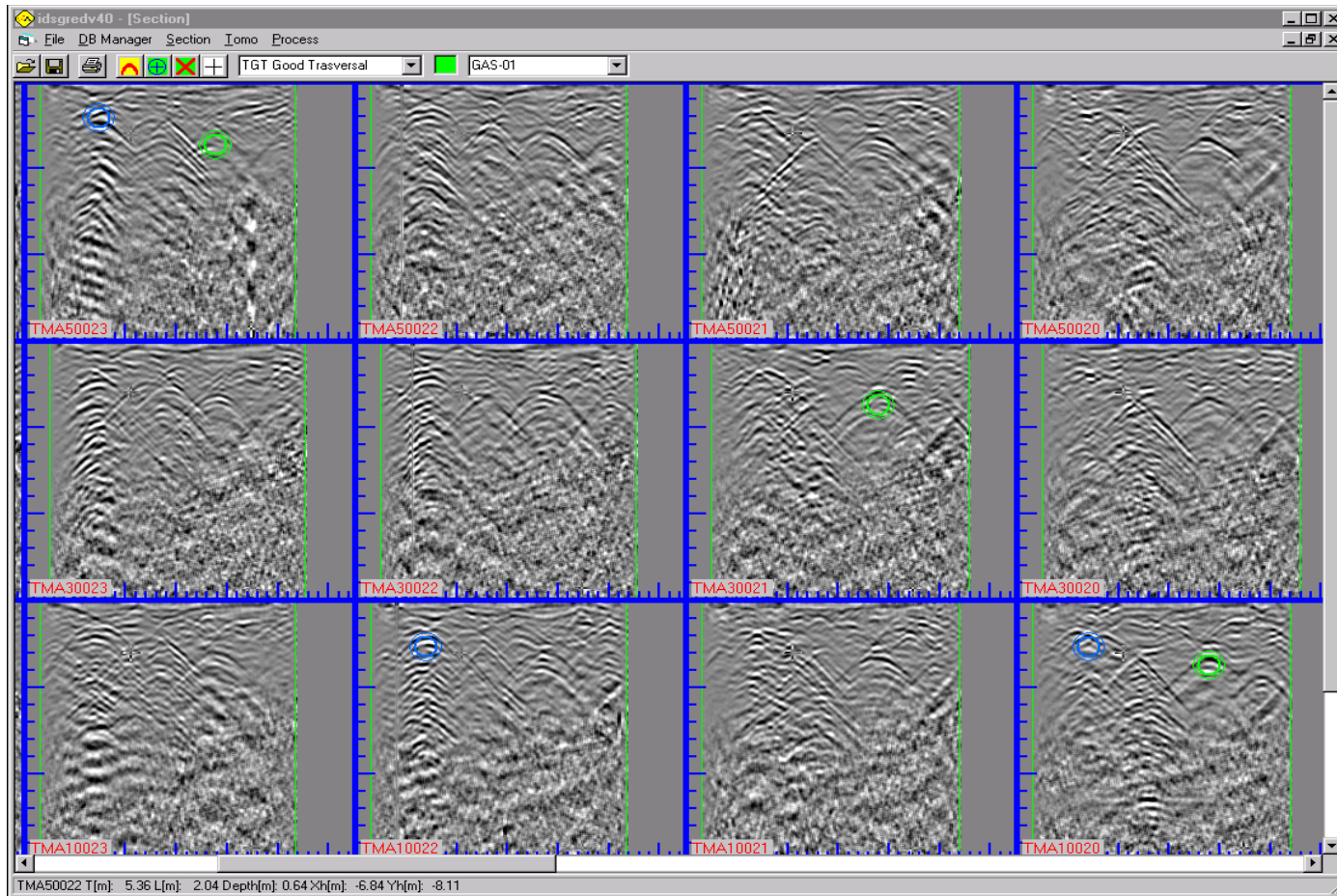
A little bit simpler...



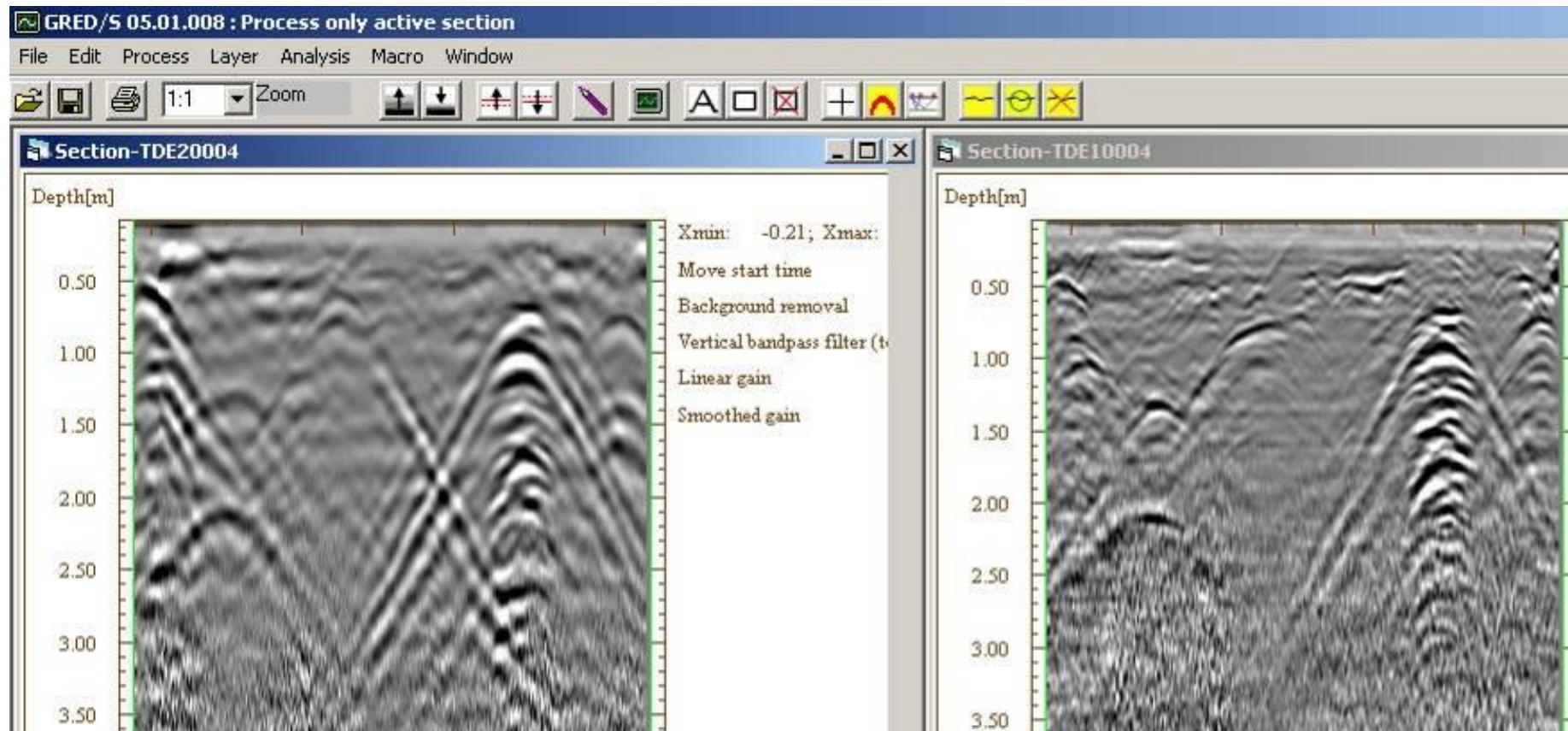
How it really looks



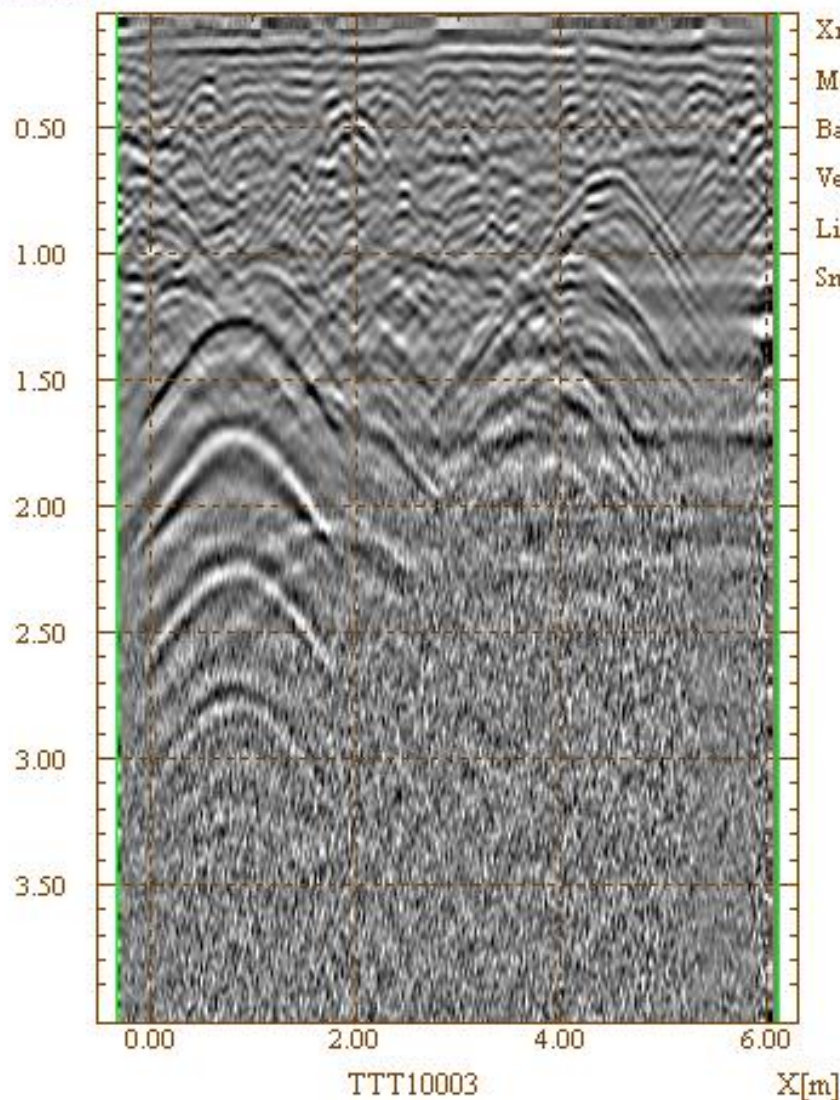
How it really looks



How it really looks



Depth[m]



Xmin: -0.31; Xmax: 6.15

Move start time

Background removal

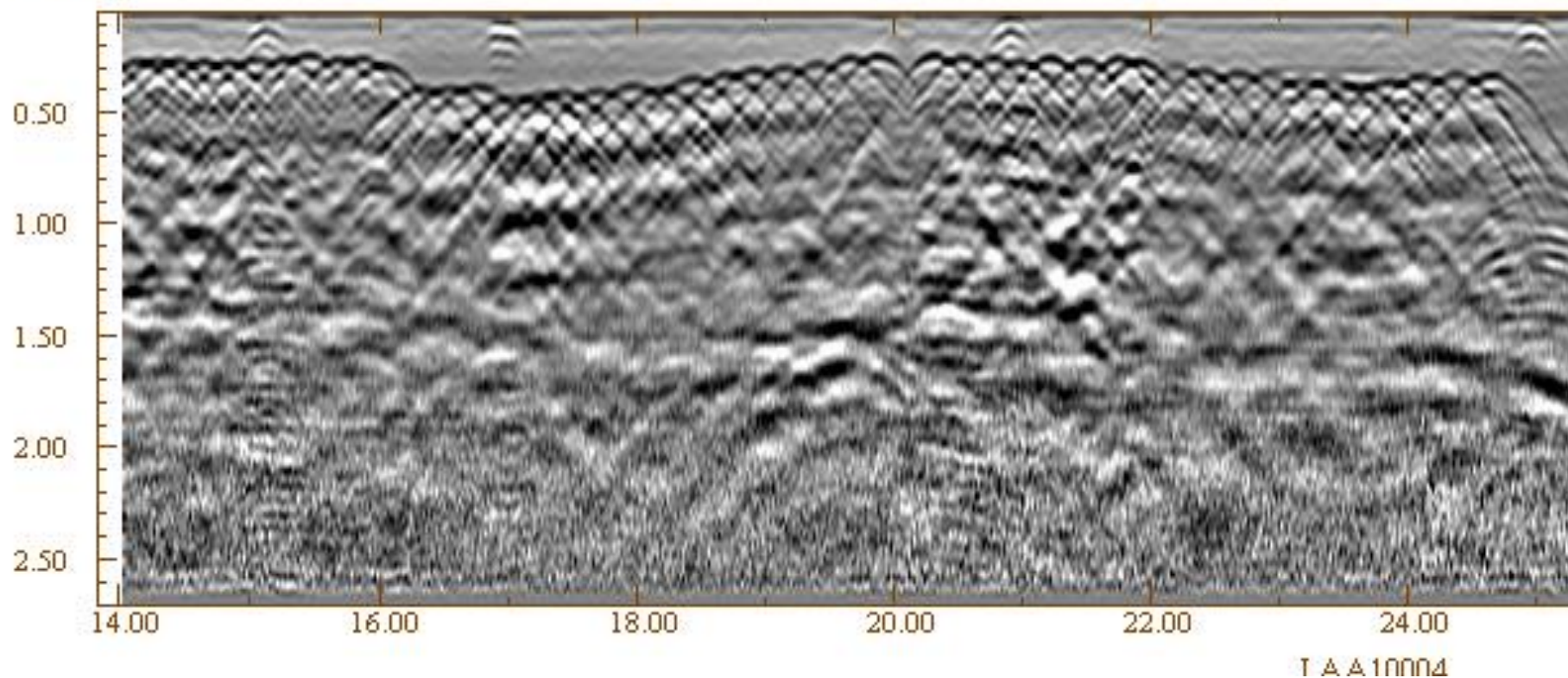
Vertical bandpass filter (td)

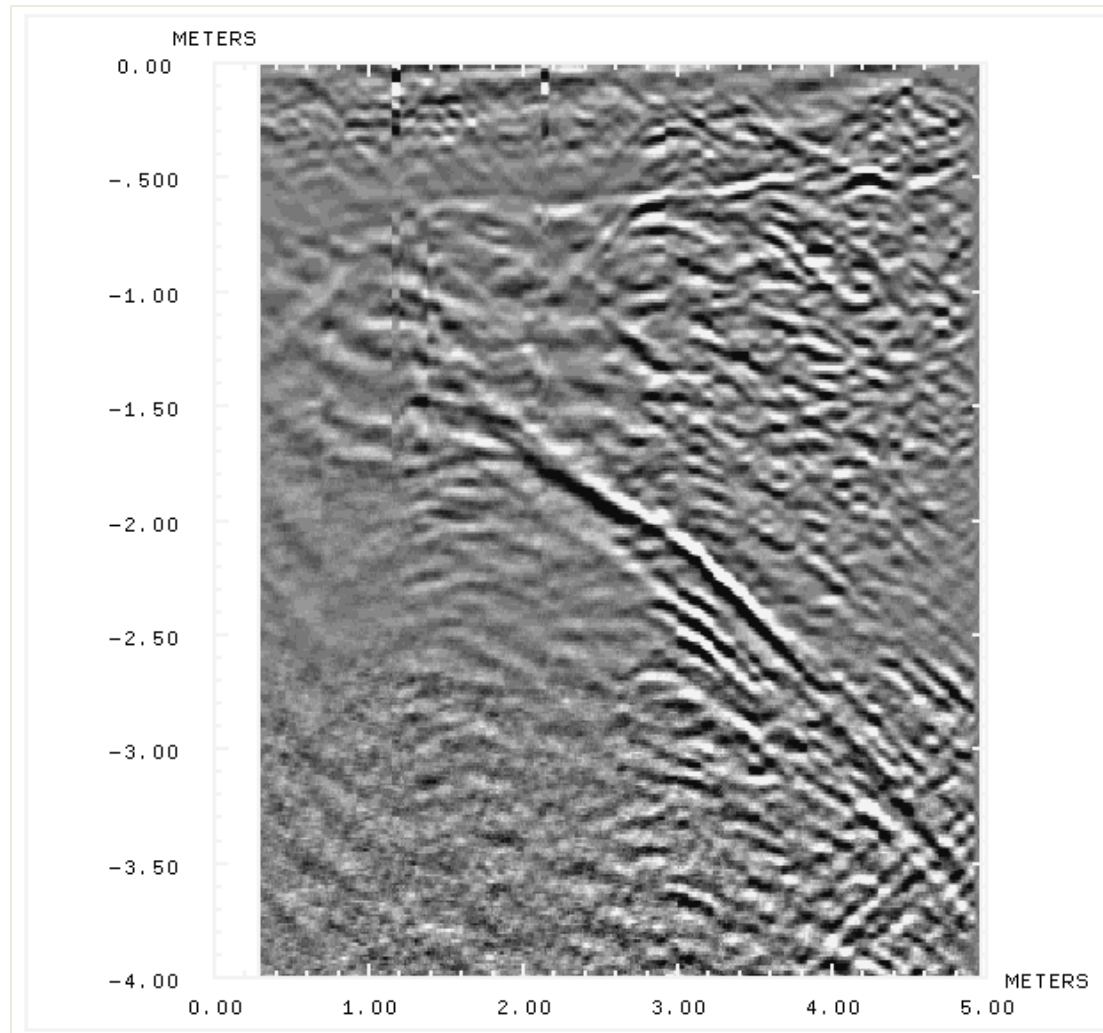
Linear gain

Smoothed gain

How it really looks

Depth[m]





Case study

Pedestrian bridge „Jean–Michel Nicolier“ is located in the center of the town Vukovar. Each year Remembrance Procession is held and sometimes almost 100.000 people walk over in the tight formation.



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Case study

The bridge appear to be in the good shape, but on closer inspection....



Case study

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Case study

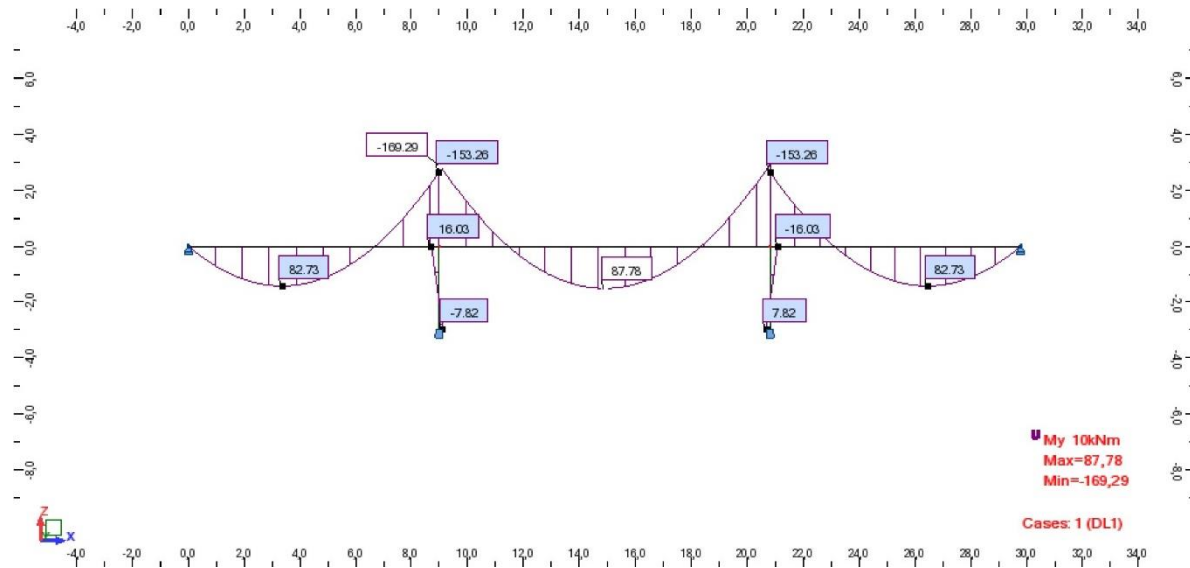
City authorities ordered emergency assessment of the bridge from the Faculty of Civil Engineering Osijek. After visual inspection, the doubt about safety of the users have been risen. Although the columns and abutments are in a good shape, the span is dangerously damaged. The reinforcement in the lower zone is completely exposed and no bond between the rebars and concrete exists.

Case study

The structure of the pedestrian bridge in Vukovar is reinforced concrete three-span frame structure 9 + 12+ 9 m. The bridge and bridge columns are most likely constructed with monolithic connection. The nominal thickness of the slab is 53 cm, but due to the degraded condition and damage to the lower zone, it can effectively be calculated with a thickness of 50 cm.

Case study

After the preliminary calculation it is confirmed that structural safety can not be guaranteed due to the high tensile stress in the lower, practically unreinforced zone.



Case study

The Remembrance Day and the Procession were very close and closing the bridge down was not an option, as a first measure we decided to limit the number of people crossing over, using the fences.



Case study

Deeper assessment of the bridge capacity should answer three questions:

1. Integrity of the structure: does the bridge act as continuous girder or is it series of the simple beams?
2. Material characteristics: the grade of the steel rebars and compression strength of the concrete is unknown.
3. How many bars of the reinforcement are installed and in which position?

Case study

So the following tests were chosen:

1. Integrity of the structure: does the bridge act as continuous girder or is it series of the simple beams?

Dynamic testing of the structure
(Non destructive technique)

Case study

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Concrete core testing
(Destructive technique)

Case study

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GPR survey
(Non destructive technique)

Case study

Dynamic testing of the structure (Non destructive technique)

Dynamic testing yields data on the vibration periods, oscillation modes and damping coefficients. Dynamic characteristics represent a personal map of the structure. Any eventual changes in dynamic characteristics after some intervention or catastrophic event point to changes in stiffness and hidden damage to the construction.

Case study

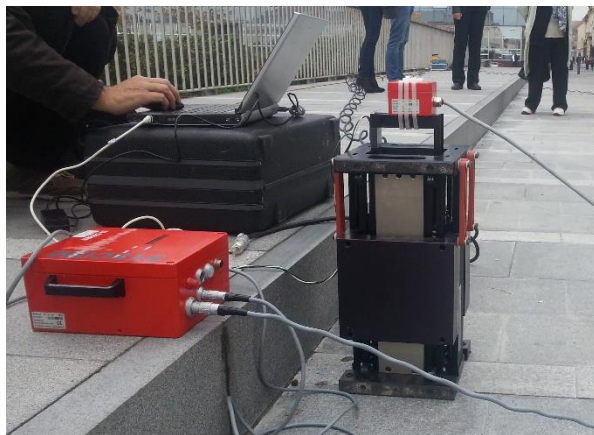
Dynamic testing of the structure (Non destructive technique)

The test was carried out in order to determine the dynamic properties of the bridge in order to:

- Comparisons of measured dynamic properties with prescribed minimum dynamic properties
- Determination of dynamic stiffness of the slab and beam for estimating the condition and deformation at load
- Determining vertical rigidity distribution and contribution of individual elements in taking vertical loads
- Determining the bearing structure of the bridge.

Case study

Dynamic testing of the structure
(Non destructive technique)



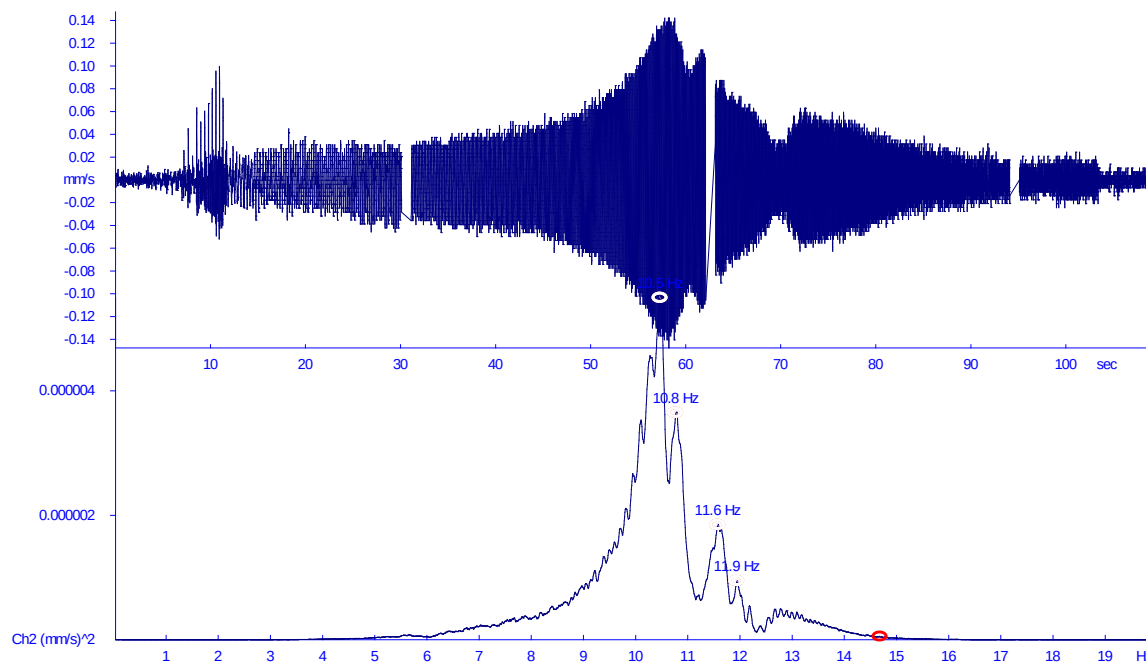
Long stroke shaker and accelerometer



Data aquisition unit

Case study

Dynamic testing of the structure
(Non destructive technique)



Time domain

Frequency domain

Case study

Dynamic testing of the structure - conclusions (Non destructive technique)

1. The bridge has clearly emphasized oscillation frequencies corresponding to the calculations for deteriorated sections and the given bridge spans.
2. The bridge, though having a clearly emphasised system's frequencies, also has a number of secondary impacts that indicate the unbound (non-homogeneous) supporting structure of the bridge, ie the presence of one basic and several secondary supporting systems.
3. Increased damping coefficients indicate non-homogeneity of the system (increased energy consumption).
4. ***The bridge acts as series of the simple beams.***

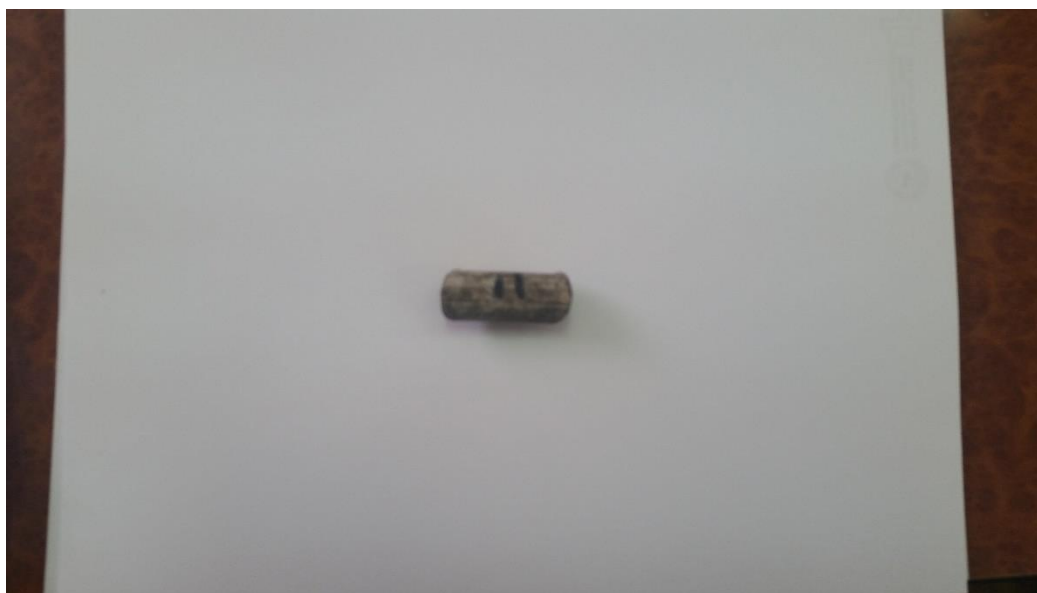
Case study

Concrete core testing (Destructive technique)



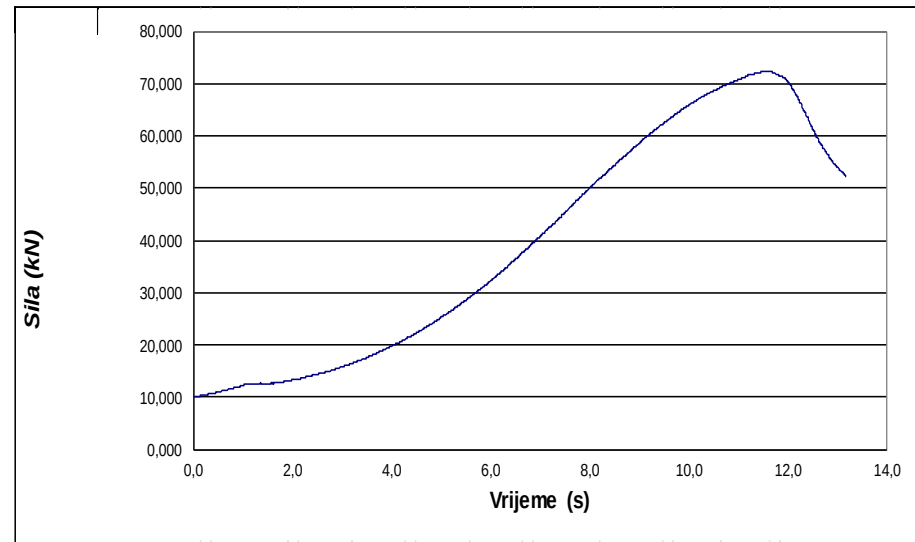
Case study

Concrete core testing
(Destructive technique)



Case study

Concrete core testing (Destructive technique)



Case study

Concrete core testing - conclusions (Destructive technique)

The estimated characteristic compressive strength of the built-in concrete according to HRN EN 13791: 2007 is lower than the following two:

$$f_{ck,is} = f_{m(n),is} - k = 57,0 - 6 = 51,0 \text{ MPa}$$

$$f_{ck,is} = f_{s(min)} + 4 = 42,5 + 4 = 46,5 \text{ Mpa}$$

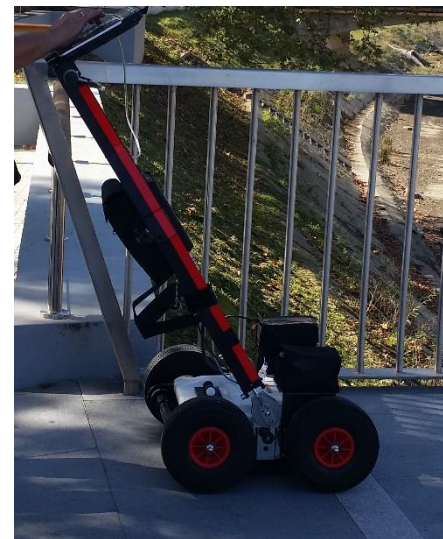
Based on the above results we can conclude that the existing concrete in the tested structural elements corresponds to the class of concrete C35 / 45.

Case study

GPR survey

(Non destructive technique)

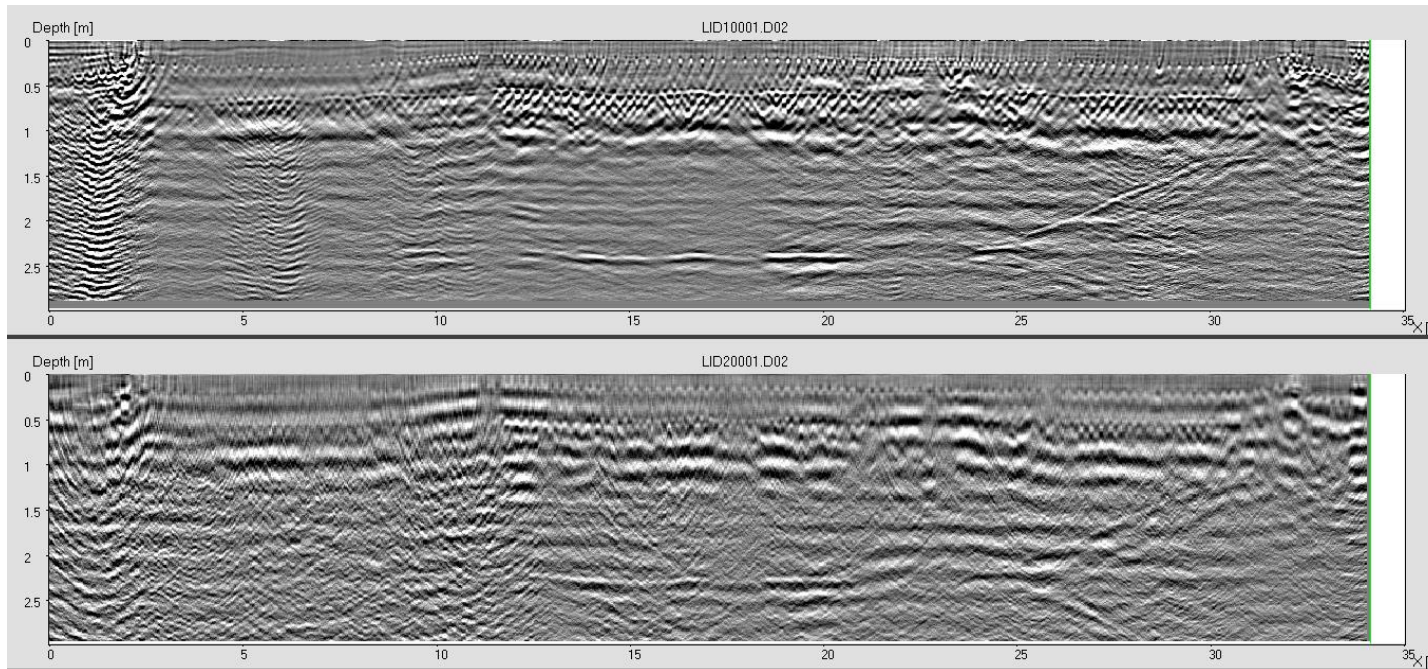
In this survey of the pedestrian bridge 2 GHz bipolar, 600 MHz and 200 MHz antennas were used. This selection of the antennas has enabled the detection of the entire spectrum of possible damages to the structure and the built-in reinforcement.



Case study

GPR survey

(Non destructive technique)



600 MHz

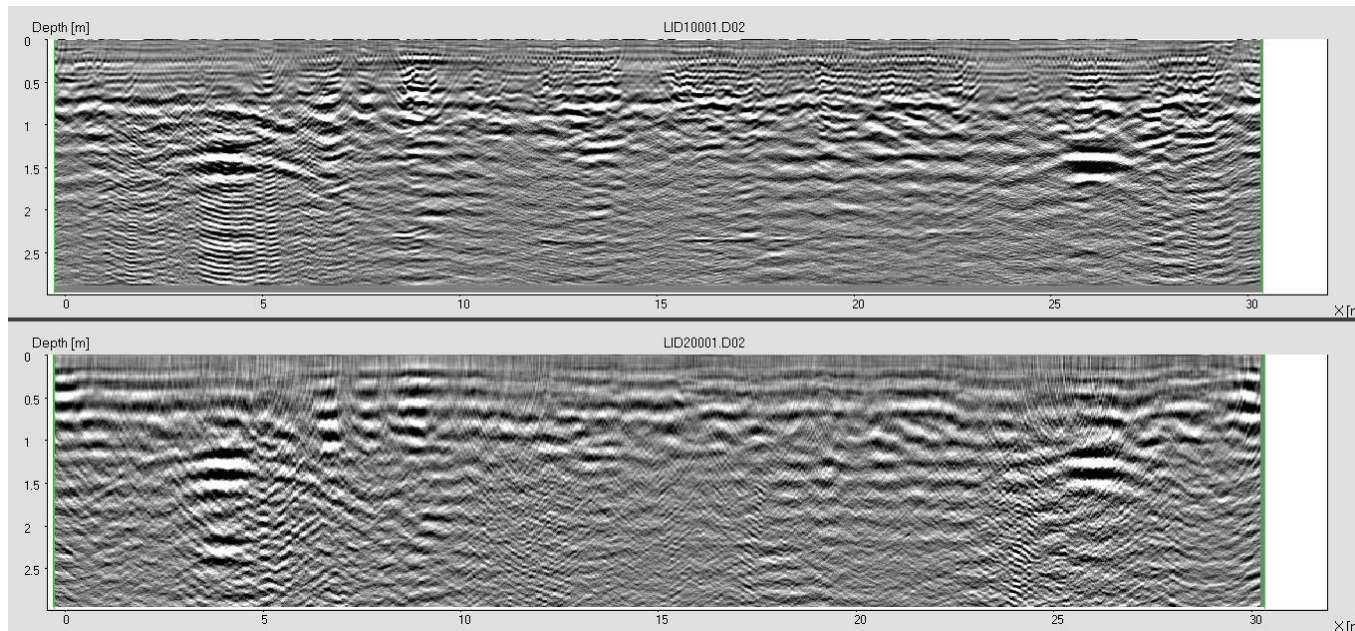
200 MHz

Radargram of the bridge in longitudinal direction

Case study

GPR survey

(Non destructive technique)

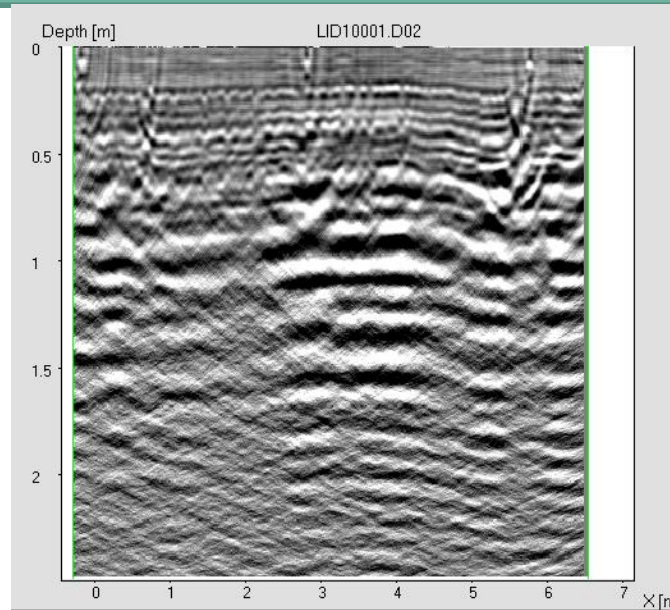


600 MHz

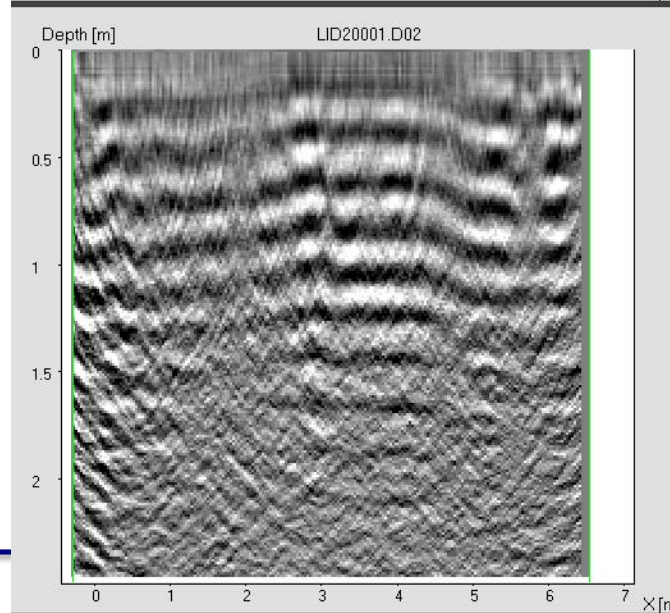
200 MHz

Radargram of the pedestrian console in longitudinal direction

Radargram of the
bridge in transversal
direction

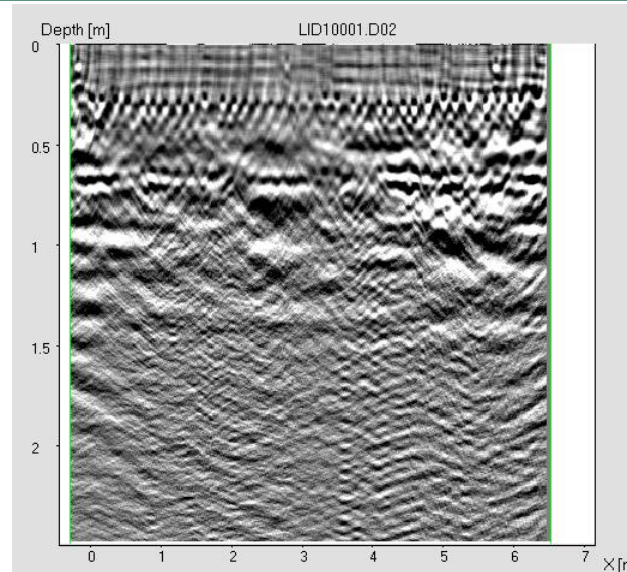


600 MHz

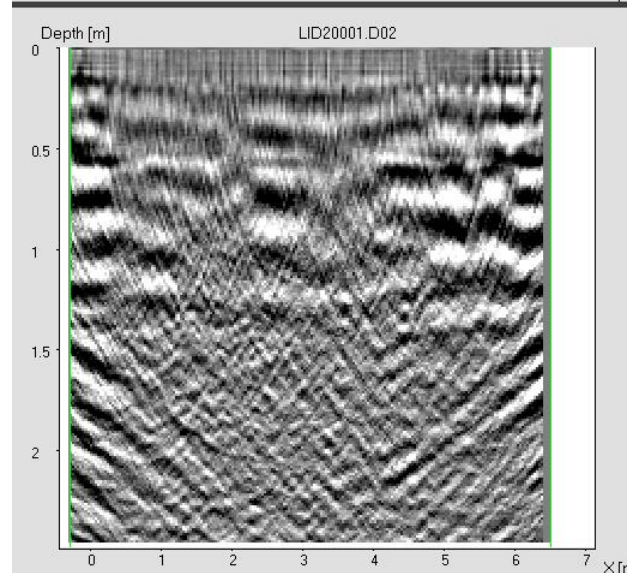


200 MHz

Radargram of the
bridge deck in
transversal direction,
over the bearings.



600 MHz



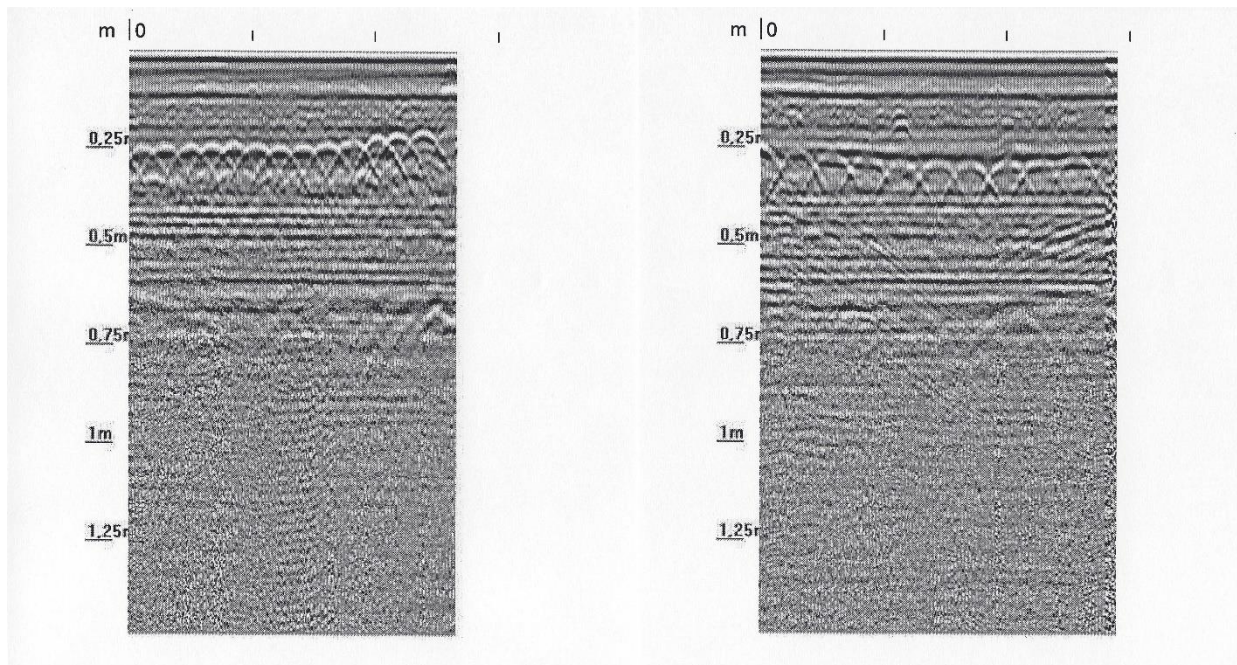
200 MHz

Case study

GPR survey

(Non destructive technique)

2 GHz



Case study

GPR survey - conclusions

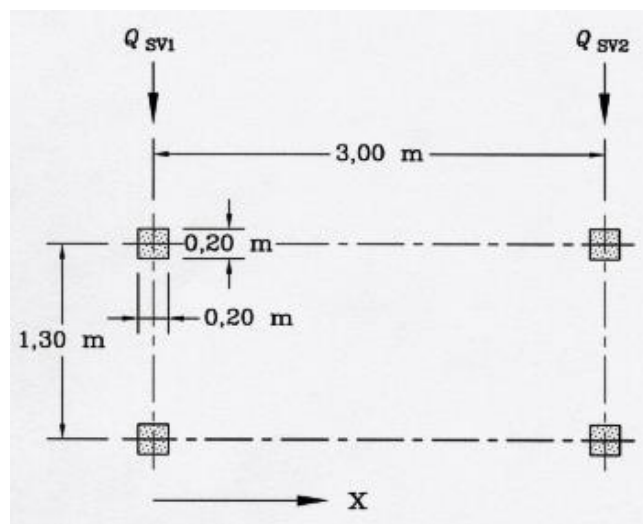
(Non destructive technique)

The survey of the span in the longitudinal direction was carried out in 5 cross-sections. There are clearly visible layers of concrete slab (stone covering, concrete slab). Within the concrete body of the structure, no large cracks or cavities were observed, so it can be considered to be in a relatively good condition. The transverse reinforcement is located at a depth of 25 - 28 cm at intervals ranging from 24 to 30 cm in the middle of the span and 15 - 21 cm above the bearings. The main longitudinal reinforcement in the upper zone is also unevenly distributed. It is located at a depth of 21 to 27 cm and at intervals ranging from 12 to 20 cm.

Case study

Verification

Based on all the results, calculation of the load capacity was carried out according to two load models: crowd by people (LM4) and Load model „Service Vehicle”.



Case study

Verification - results

$$\sigma_d = \frac{17020}{41666} = 0,41 \text{ kN} / \text{cm}^2 = 4,1 \text{ N} / \text{mm}^2 > f_{ct,m} = 2,13 \text{ N} / \text{mm}^2$$

$$q_{fk} = 2,0 + \frac{120}{L + 30} \text{ kN/m}^2$$

$$q_{fk} \geq 2,5 \text{ kN/m}^2; q_{fk} \leq 5,0 \text{ kN/m}^2$$

$$\mu_{Sd} = \frac{32004}{100 \cdot 33^2 \cdot 2,33} = 0,126 \Rightarrow \varepsilon_{c2} = -3,5\text{‰}$$

$$\varepsilon_{s1} = 14\text{‰}$$

$$\zeta = 0,917$$

$$\mu_{Sd} = \frac{30174}{100 \cdot 33^2 \cdot 2,33} = 0,119 \Rightarrow \varepsilon_{c2} = -2,6\text{‰}$$

$$\varepsilon_{s1} = 10\text{‰}$$

$$\zeta = 0,919$$

$$A_{s1} = \frac{32004}{0,917 \cdot 33 \cdot 20,86} = 50,70 \text{ cm}^2 < A_{s1,stv} = 6 \cdot 2,01 = 12,06 \text{ cm}^2$$

$$M_{Sd,max} = f_{ct,m} \cdot W = 0,32 \cdot 41666 = 133,33 \text{ kNm}$$

$$A_{s1} = \frac{30174}{0,919 \cdot 33 \cdot 20,86} = 47,69 \text{ cm}^2$$

$$V_{Rd1} = [0,037 \cdot 1,1(1,2 + 40 \cdot 0) + 0,15 \cdot 0] \cdot 100 \cdot 50 = 203,50 \text{ kN} > V_{Sd} = 163,43 \text{ kN}$$

$$V_{Rd1} = [0,037 \cdot 1,1(1,2 + 40 \cdot 0) + 0,15 \cdot 0] \cdot 100 \cdot 50 = 203,50 \text{ kN} > V_{Sd} = 201,43 \text{ kN}$$

$$q_{fk} = 2,0 + \frac{120}{29,8 + 30} \text{ kN/m}^2 = 4,00 \text{ kN} / \text{m}^2$$

Case study

Verification - results

The tensile stresses for the LM4 in the lower zone exceed the mean design tensile strength.

The tensile stresses for the service vehicle in the lower zone exceed the mean design tensile strength.

There is not enough reinforcement for LM4 over the bearing.

There is not enough reinforcement for service vehicle over the bearing.

Load capacity on the transverse forces is satisfactory.

Tensile stresses for reduced traffic loads in the lower zone exceed the mean design tensile strength.

In cross-section over the bearing there is not enough reinforcement to take over the reduced traffic load.

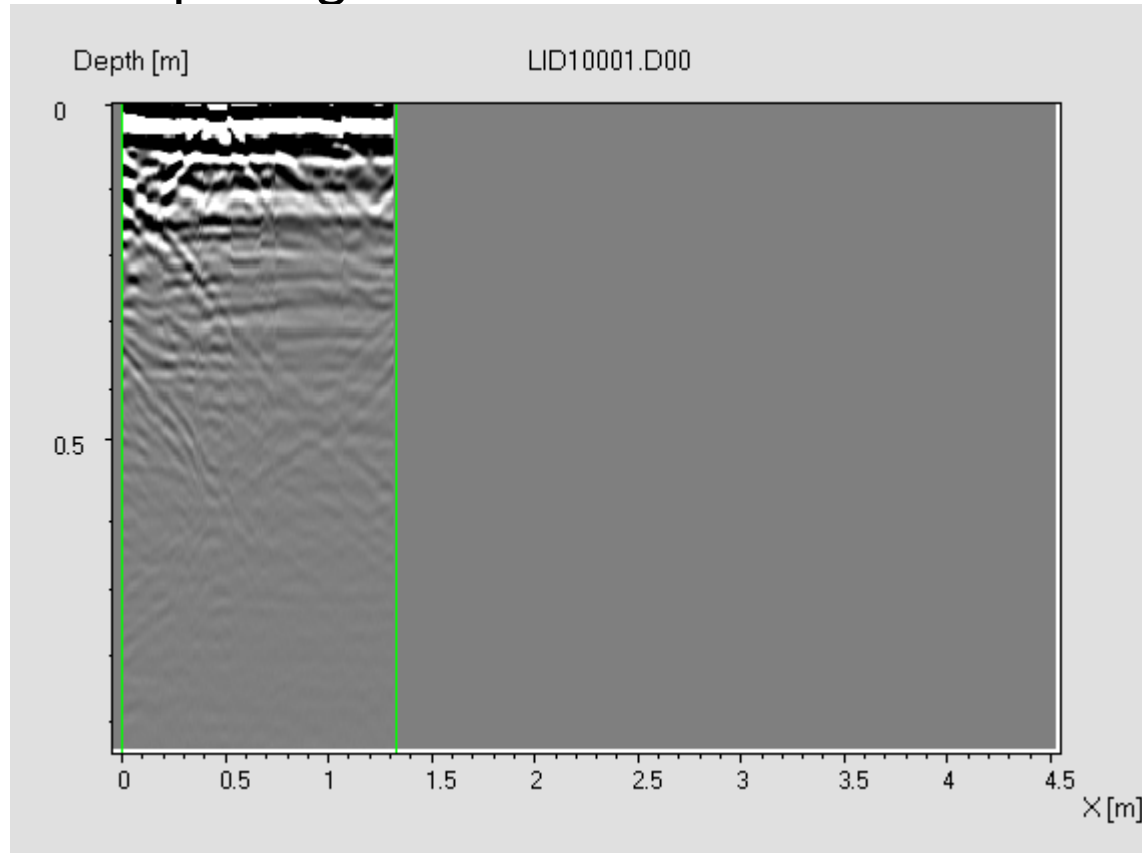
Some interesting surveys

Hidden passage behind the Roman tombstone?



Some interesting surveys

Hidden passage behind the Roman tombstone?



900 MHz

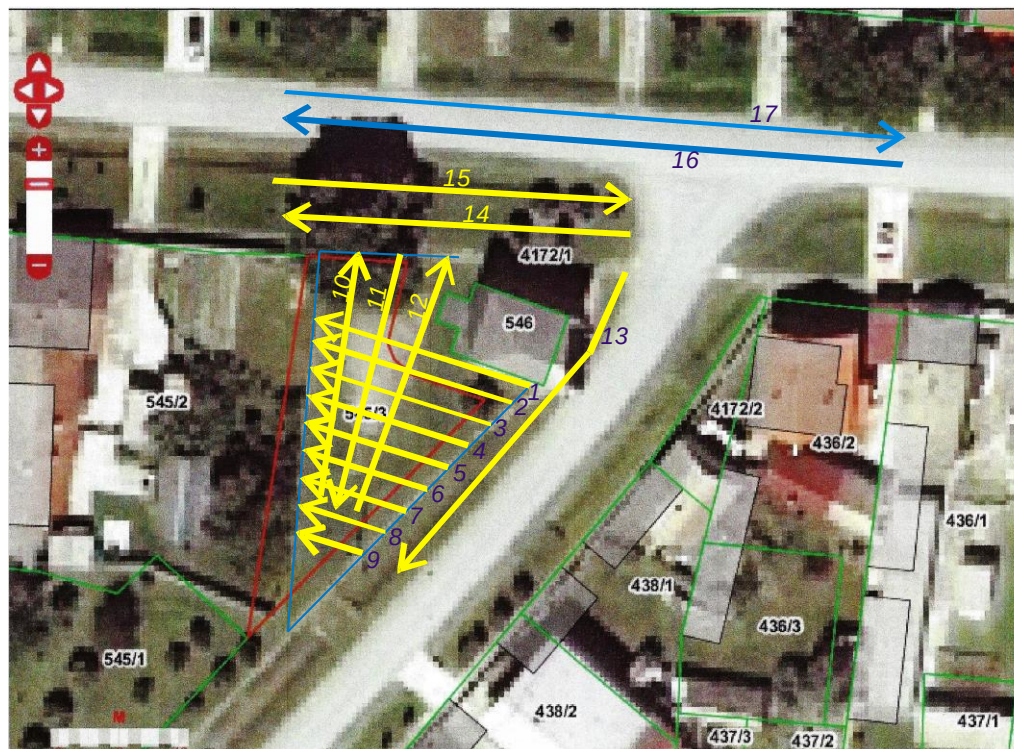
Some interesting surveys

Medieval chappel in Gorjani – is there a underground tunnel to the castle?



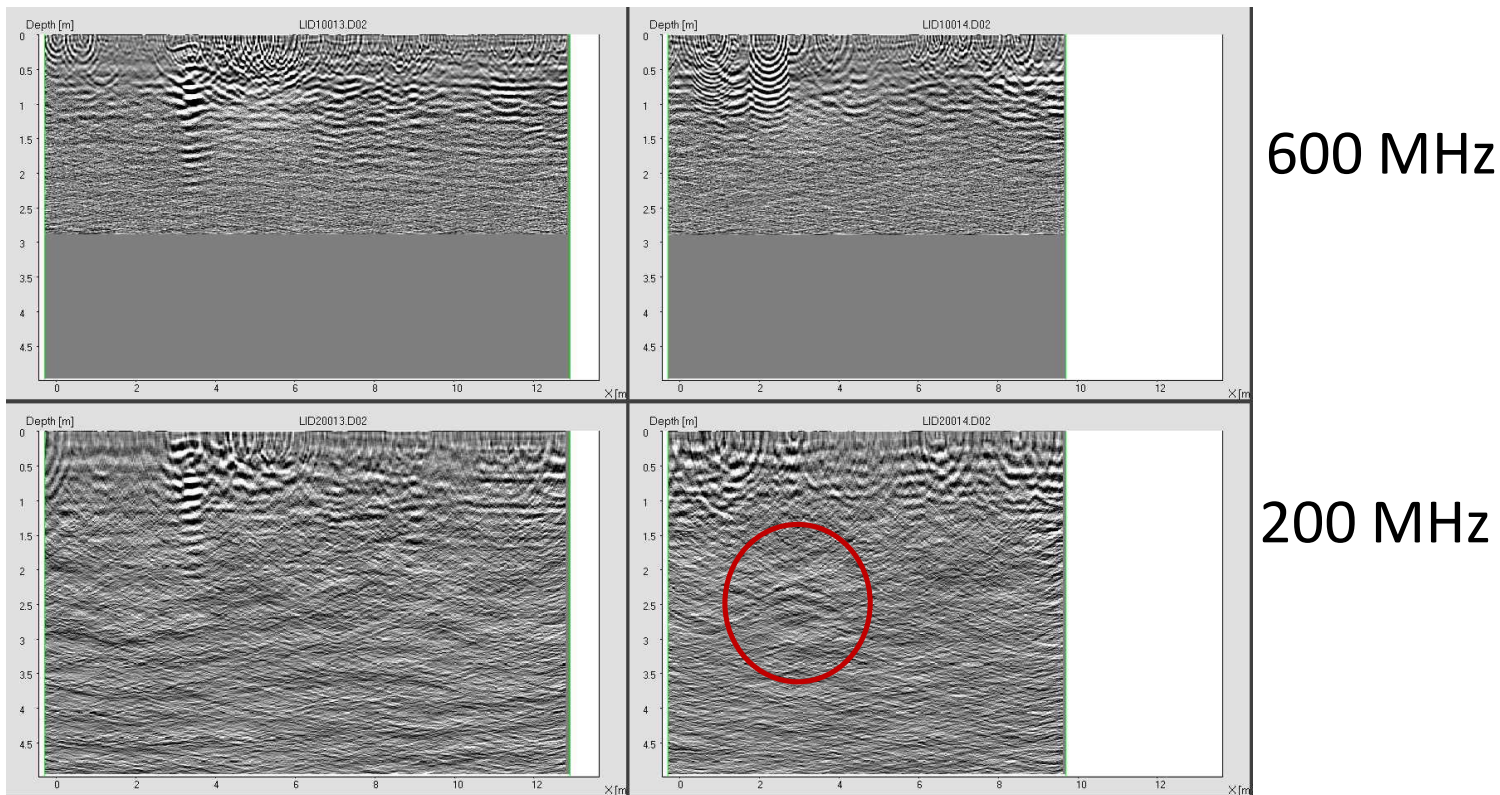
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Some interesting surveys

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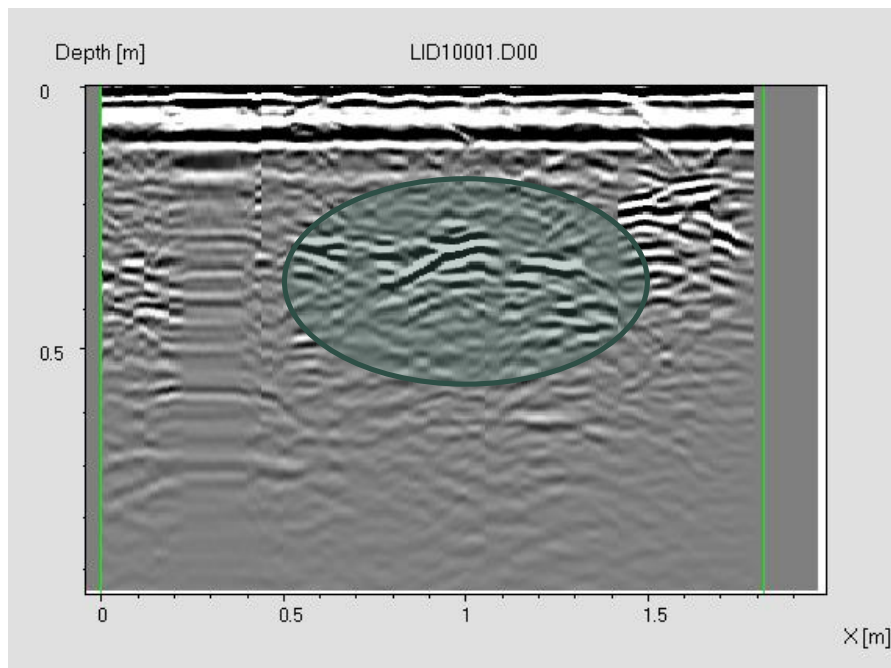
Some interesting surveys

15th century monastery on the island Badija – composition of the walls and structural integrity



Some interesting surveys

15th century monastery on the island Badija – composition of the walls and structural integrity



900 MHz

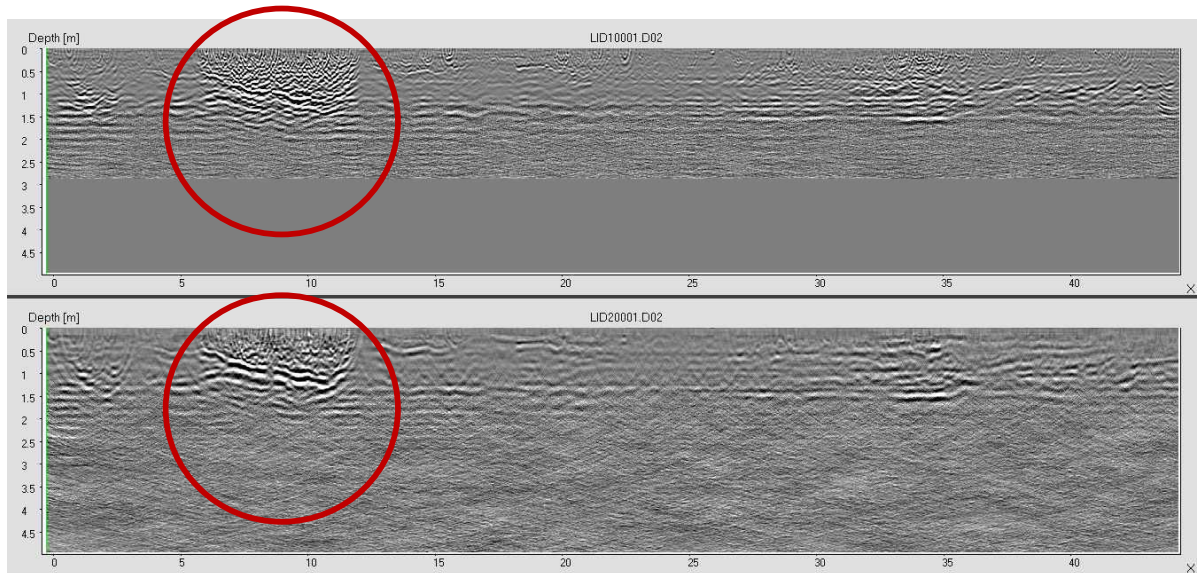
Some interesting surveys

13th century castle Kororođvar – was there a waterway between river and inner water trench?



Some interesting surveys

13th century castle Kororođvar – was there a waterway between river and inner water trench?



600 MHz

200 MHz

Final word...

Georadar is not a „miracle” tool. As any other non-destructive technique, it has advantages and disadvantages.

The best way to use GPR is in combination with other NDT and/or DTs.

In this case, without the data provided by GPR this assessment would not be possible.

Thank you for your attention!

NOTE:

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