4th International Conference on Structural Integrity

Funchal, Madeira, Portugal
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Symposium I - Structural Integrity of steel/FRP & concrete composite structures

An approach for assessment of concrete deterioration by surface waves

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Monday, 30/Aug/2021 9:30pm - 10:00pm, Room C

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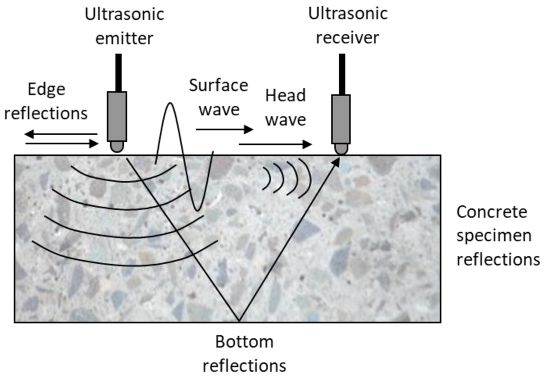
1. Problem concrete degradation and loss of structural integrity due to surface deterioration

- Freezing - thawing cycles
- Chemical corrosion (environment with reduced pH-acids, sulphates, chlorides, sea water)
- Carbonization
- High temperatures, fire
- Abrasive effect and leaching
- Simultaneous effects of several factors

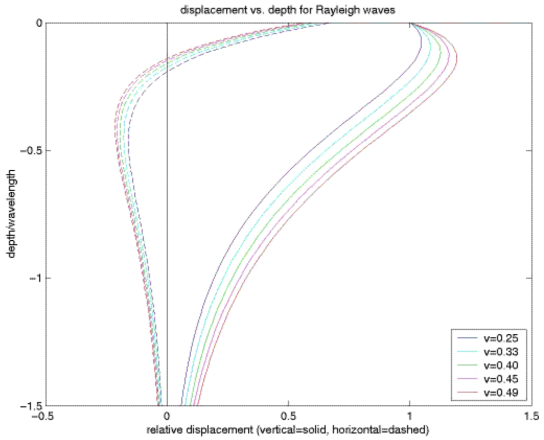
Exposed concrete surface degradation:
- cracking,
- scalling,
- delamination

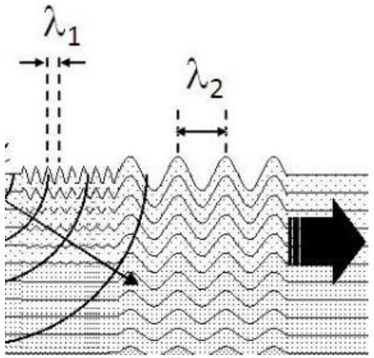
Ultrasound Pulse Velocity meter use to measure a single parameter



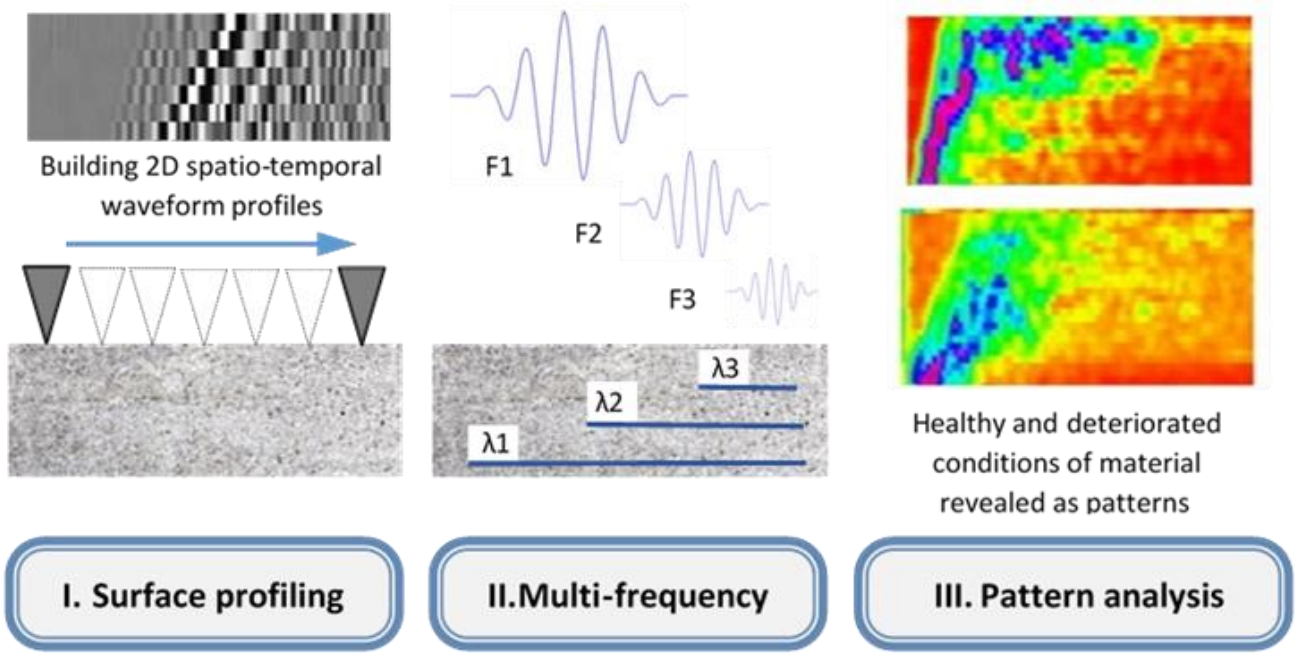
Purpose of the study:
To explore an ultrasonic testing method for assessment of concrete by the depth and the degree of degradation of the surface layer using elements of AI

2. Method of ultrasonic testing of surface layer quality using surface waves



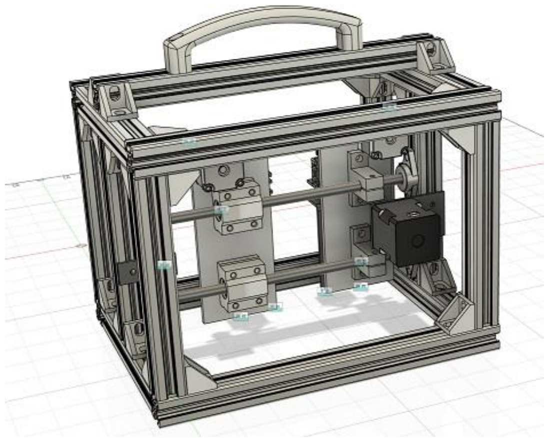


Penetration depth of surface waves into material is a function of wavelength (frequency)

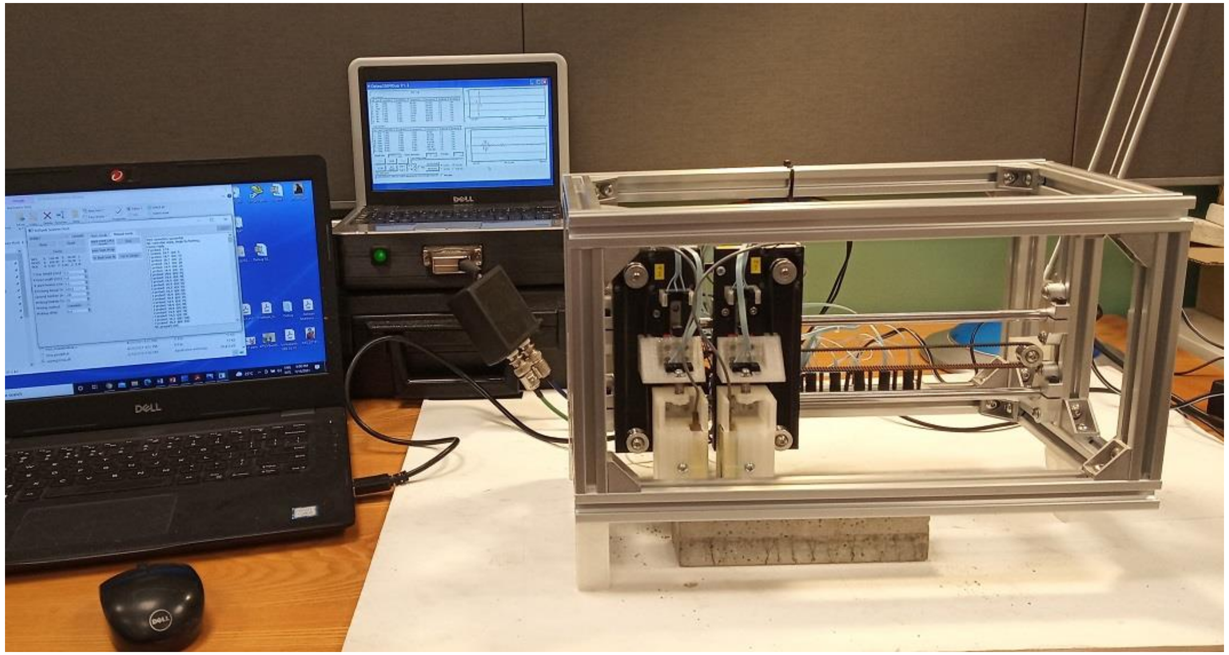


2D spatiotemporal waveform profiles at several frequencies – raw material for analysis

3. Experiment: Ultrasonic surface scanner and ultrasonic data acquisition



Motor-driven ultrasonic scanning setup



Acquisition parameters:

- Surface profiling 30…80 mm, step 5 mm (21 signal in a profile)
- Excitation signal: Modulated 2-period sine tone burst
- Frequencies: 50 kHz; 100 kHz; 200 kHz in a train

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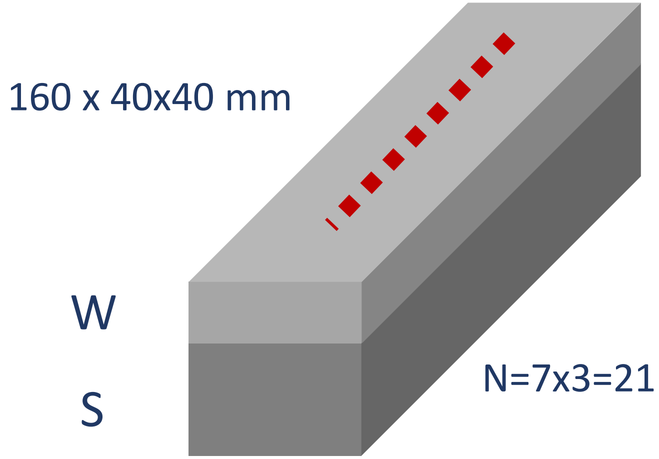
3.1. Specimens design

2 factors-of-interest (FOI):

- Depth of deteriorated (weak) surface layer
- Degree of deterioration (weakness)

Modelling:

- Varied thickness of weak surface layer in 2-layer specimen
- Degree of weakness varied by cement content and controlled by ultrasound velocity values



Thicknesses ratio of weak (W) and strong (S) layers:
For building model: 0:40; 5:35; 10:30; 20:20; 30:10; 35:5; 40:0 (7 grades)
Control cases: 3:37; 25:15

Concrete quality (3 grades)	S	W1	W2	W3
Cement/sand ratio	1:3	1:4	1:7	1:12
Ultrasound velocity, m/s	4400	3900	3100	2200
Predicted strength, MPa	36	25	14	8

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4. Ultrasonic surface profiles in 2-layer concrete specimens at 50 kHz: effects of depth and degree of “weakness” (W)

Thickness of weak layer

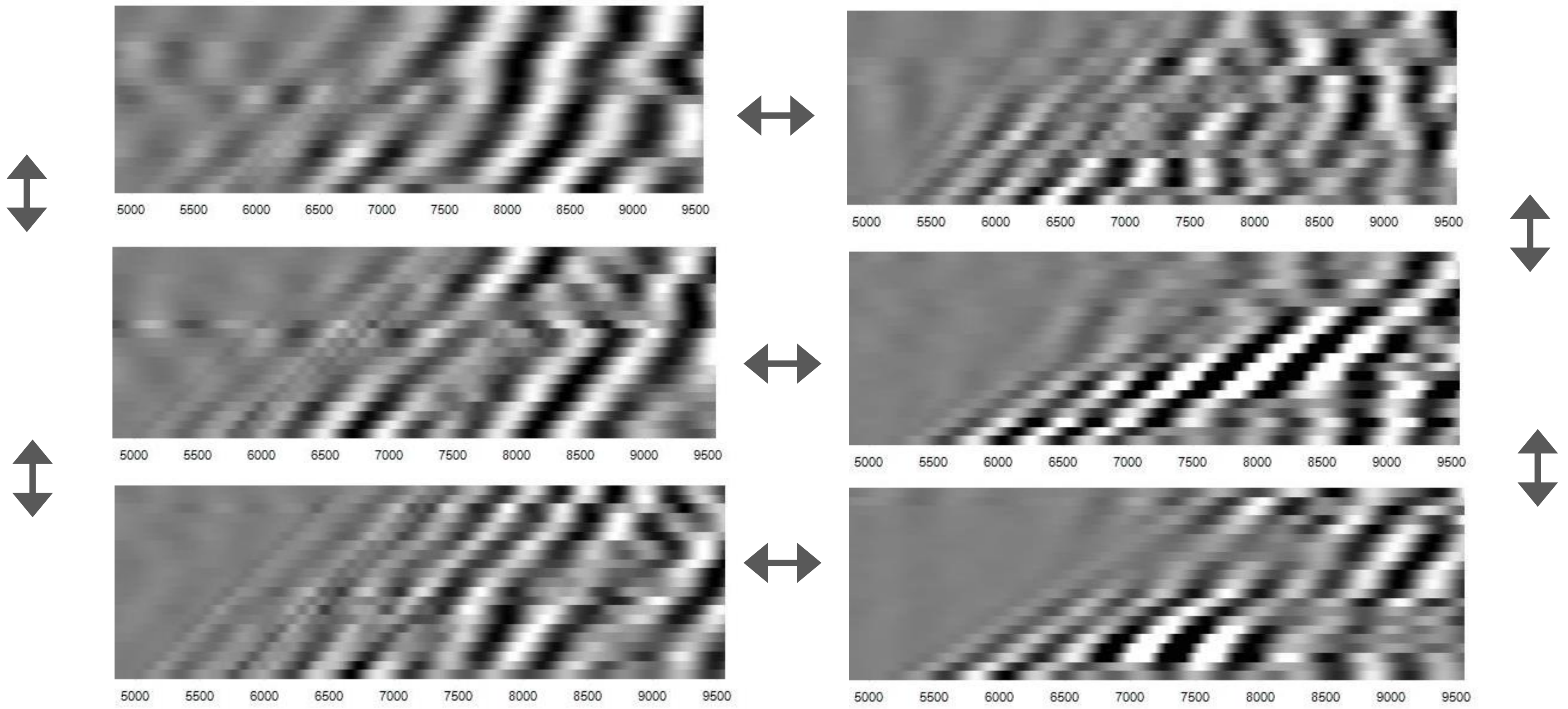
W1

W3

5 mm

10 mm

20 mm



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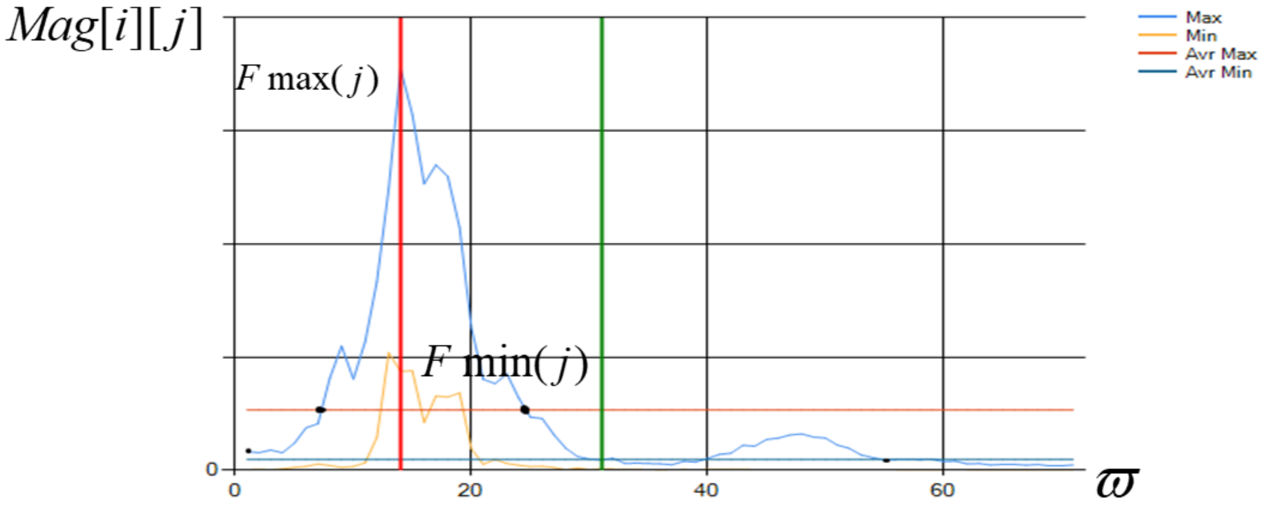
5. Pattern recognition applied to ultrasonic data

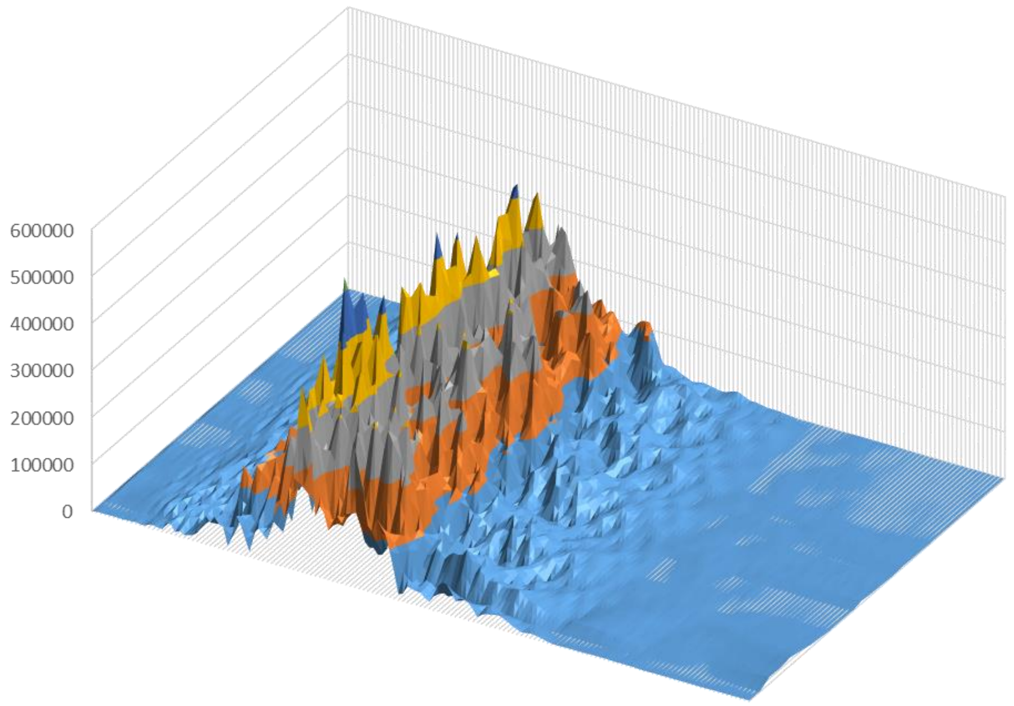
5.1. Signals conversion to frequency domain using Digital Fourier Transform and calculation F max and F min

$$\mathrm{Re}[i][j] = \sum_{n=0}^{N-1} x[i][n] \cdot \cos\left[\frac{2 \cdot \pi \cdot n \cdot j}{N}\right]$$

$$\mathrm{Im}[i][j] = \sum_{n=0}^{N-1} - x[i][n] \cdot \sin\left[\frac{2 \cdot \pi \cdot n \cdot j}{N}\right]$$

$$Mag[i][j] = \sqrt{(\mathrm{Re}[i][j])^2 + (\mathrm{Im}[i][j])^2}$$





Example of DFT signal of a single examination

5. Pattern recognition applied to ultrasonic data

5.2. Calculation of statistical criteria

- In the selected interval ω, the values of three functions were calculated:
- $F\_max(\omega) = max\{M(\omega)\};$
- $F\_avr(\omega) = average\{M(\omega)\};$
- $F\_min(\omega) = min\{M(\omega)\}$

- **Critera #6, #7 and #8:**

$$\begin{pmatrix} cr\#6 \\ cr\#7 \\ cr\#8 \end{pmatrix} = \begin{pmatrix} \sum_i \omega_i^4 & \sum_i \omega_i^3 & \sum_i \omega_i^2 \\ \sum_i \omega_i^3 & \sum_i \omega_i^2 & \sum_i \omega_i \\ \sum_i \omega_i^2 & \sum_i \omega_i & \omega_{max} - \omega_{min} \end{pmatrix}^{-1} \cdot \begin{pmatrix} \sum_i \omega_i^2 \cdot F\_max(\omega) \\ \sum_i \omega_i \cdot F\_max(\omega) \\ \sum_i F\_max(\omega) \end{pmatrix}$$

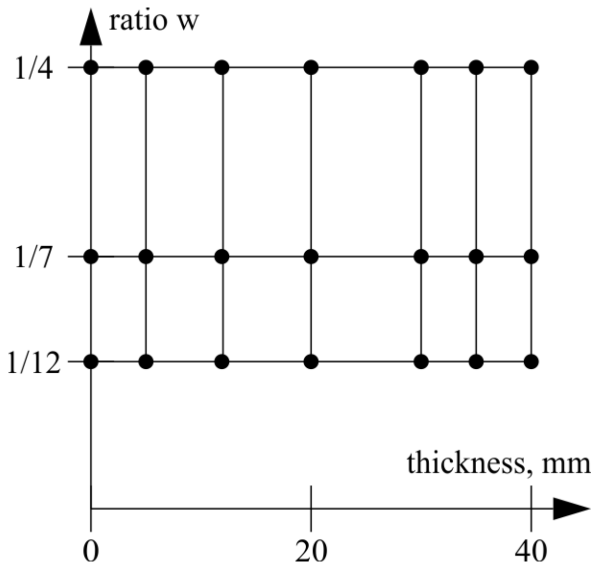
- **Criterion #1:** the number of ω values that fulfill the condition: $F_{max(\omega)} \geq average\left(F\_max(\omega)\right), (cr\#1);$
- **Criterion #2:** $cr\#2 = \frac{max\left(F\_min(\omega)\right)}{max\left(F\_max(\omega)\right)}$
- **Criterion #3:** $cr\#3 = \frac{max|dF\_max(\omega)|}{max\left(F\_max(\omega)\right)}$
- **Criterion #4:** $cr\#4 = \frac{max|dF\_avr(\omega)|}{max\left(F\_max(\omega)\right)}$
- **Criterion #5:** $cr\#5 = \frac{max|dF\_min(\omega)|}{max\left(F\_max(\omega)\right)}$
- **Criterion #9:** $cr\#9 = \frac{max\left(F\_avr(\omega)\right)}{max\left(F\_max(\omega)\right)}$

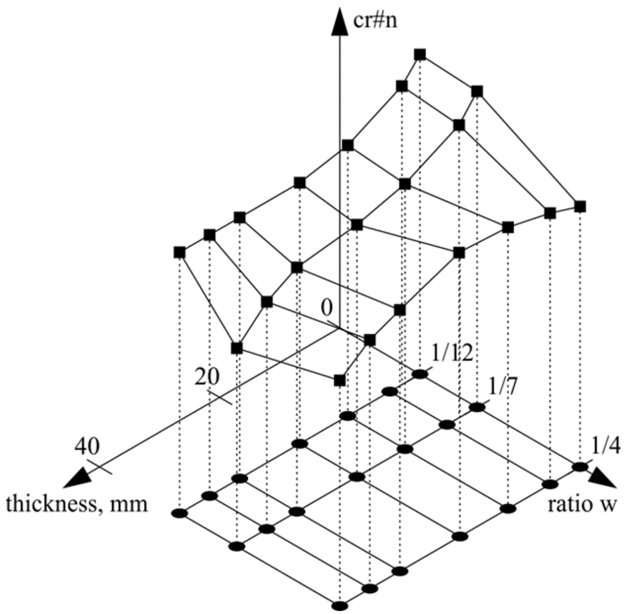
- **Criteria #10 - #13:**
- $cr\#10 = \frac{S_{min}}{S_{max}};$
- $cr\#11 = \frac{S_{avr}}{S_{max}};$
- $cr\#12 = \frac{S_{max} - S_{avr}}{S_{max}};$
- $cr\#13 = \frac{S_{avr} - S_{min}}{S_{max}}$

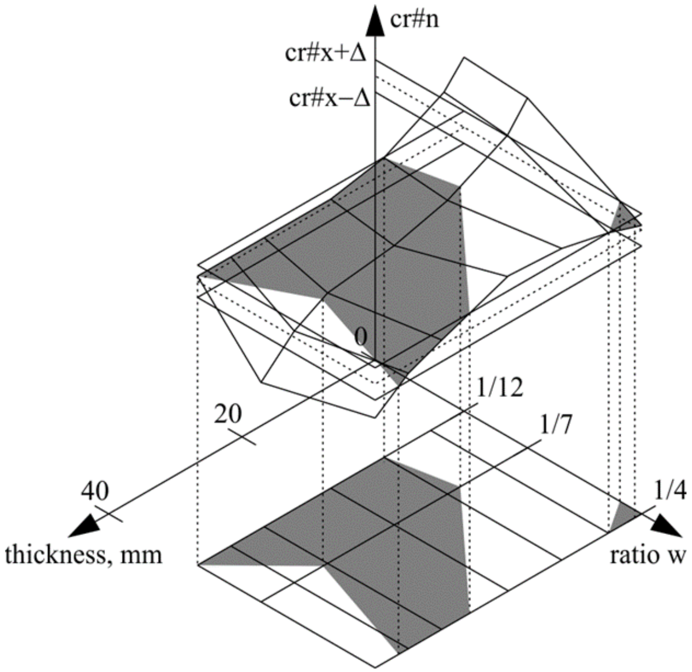
- where:
- $S_{min} = \frac{\sum_{\omega=\omega\_min}^{\omega\_max} F\_min(\omega)}{max\{F\_max(\omega)\}}$
- $S_{avr} = \frac{\sum_{\omega=\omega\_min}^{\omega\_max} F\_avr(\omega)}{max\{F\_max(\omega)\}}$
- $S_{max} = \frac{\sum_{\omega=\omega\_min}^{\omega\_max} F\_max(\omega)}{max\{F\_max(\omega)\}}$

5. Pattern recognition applied to ultrasonic data

5.3. Creation and use of decision rules







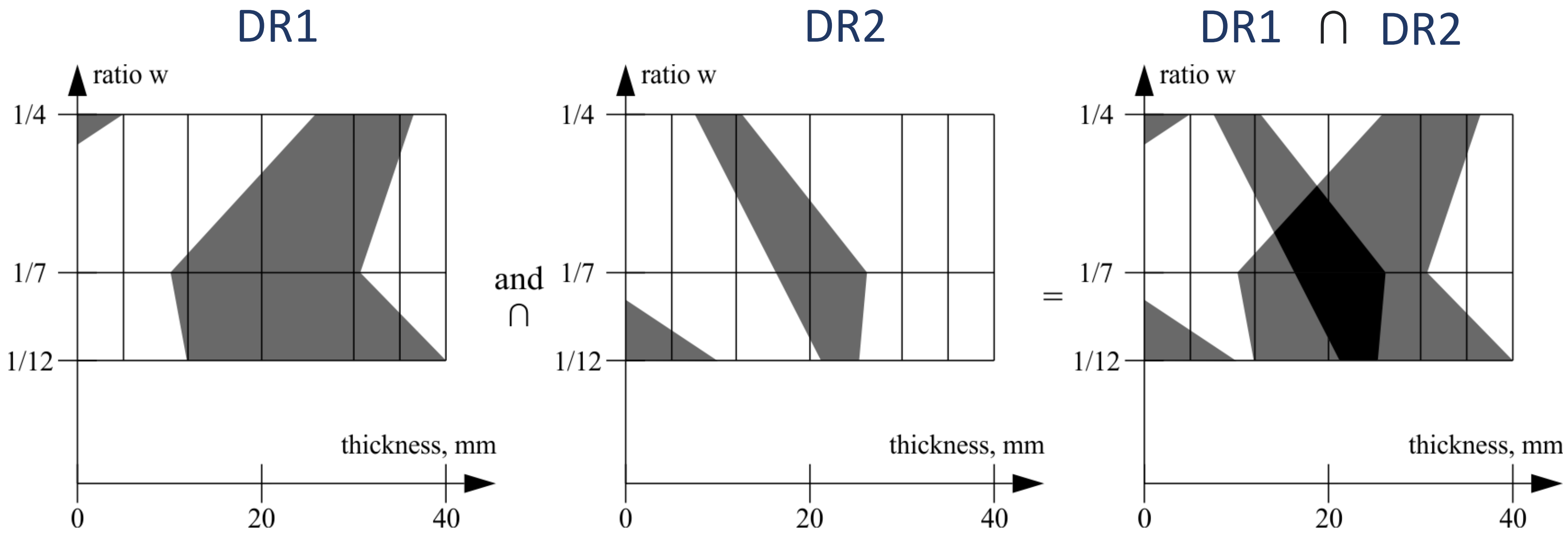
Specimens network according to FOI (thickness/depth and strength of weak layer) with a-priori known values.
Each object is described by set of discrete time signals.

Decision rule is a 2D function (bilinear or bi-square), were x,y are FOI and z is the criterion value.
13 criteria x 3 frequencies = 39 decision rules

Definition of the area of probable solutions for an object with unknown FOI within the admissible interval of deviations for the selected criterion (±5%)

5. Pattern recognition applied to ultrasonic data

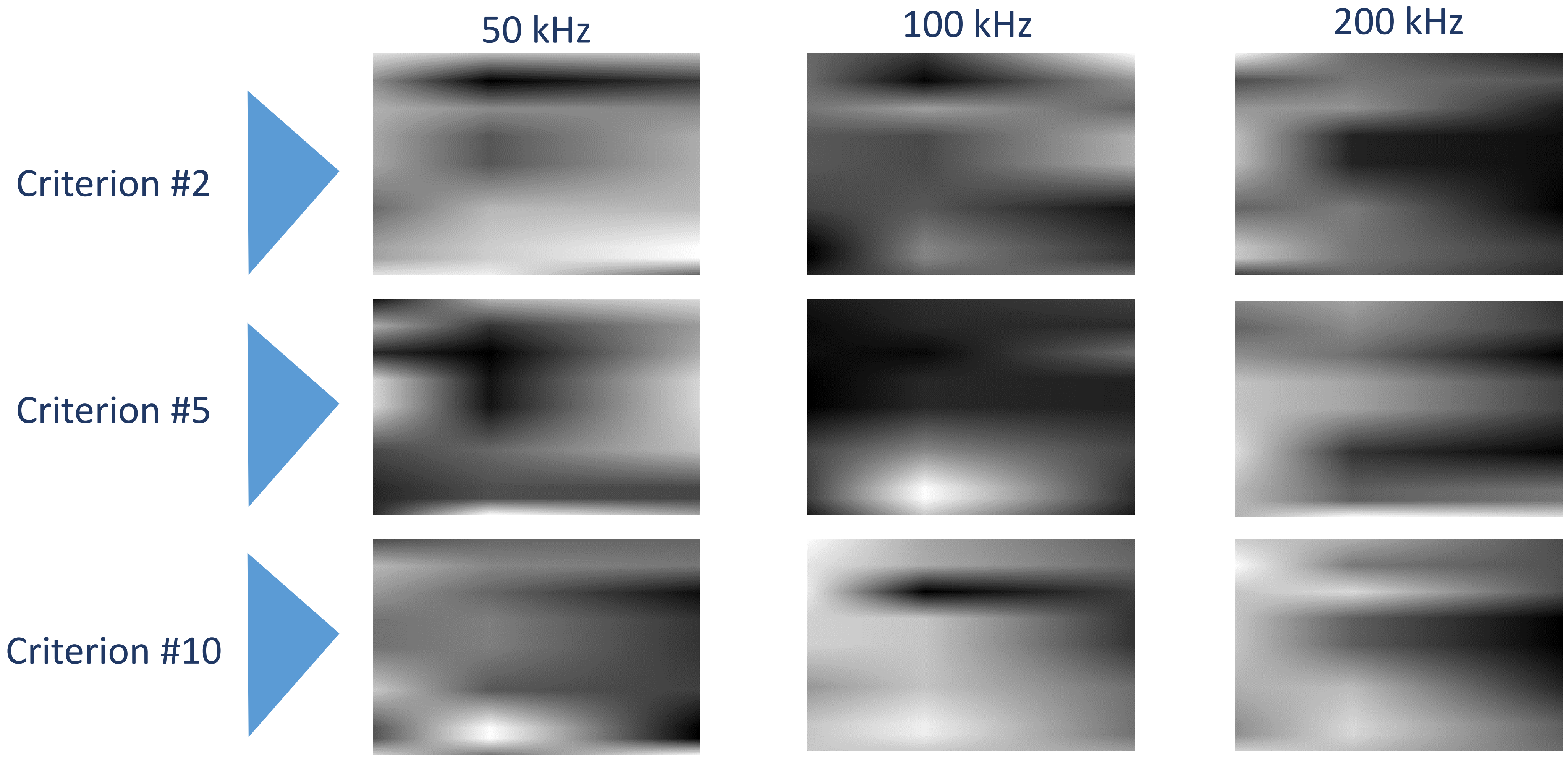
5.3. Creation and use of decision rules



Example of intersection of 2 decisions rules to concretize the area of finding the statistically true solution

5. Pattern recognition applied to ultrasonic data

5.3. Creation and use of decision rules



Examples of decision rules presented in brightness scale for selected criteria

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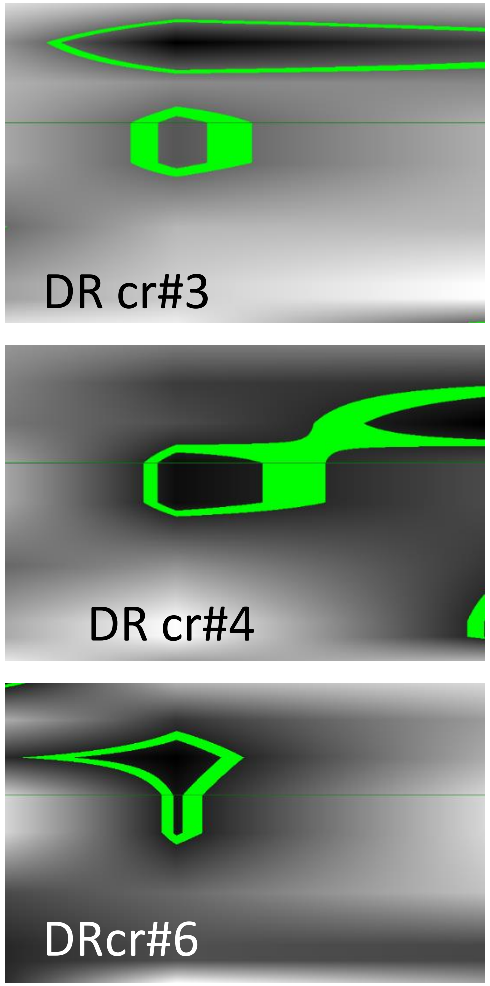
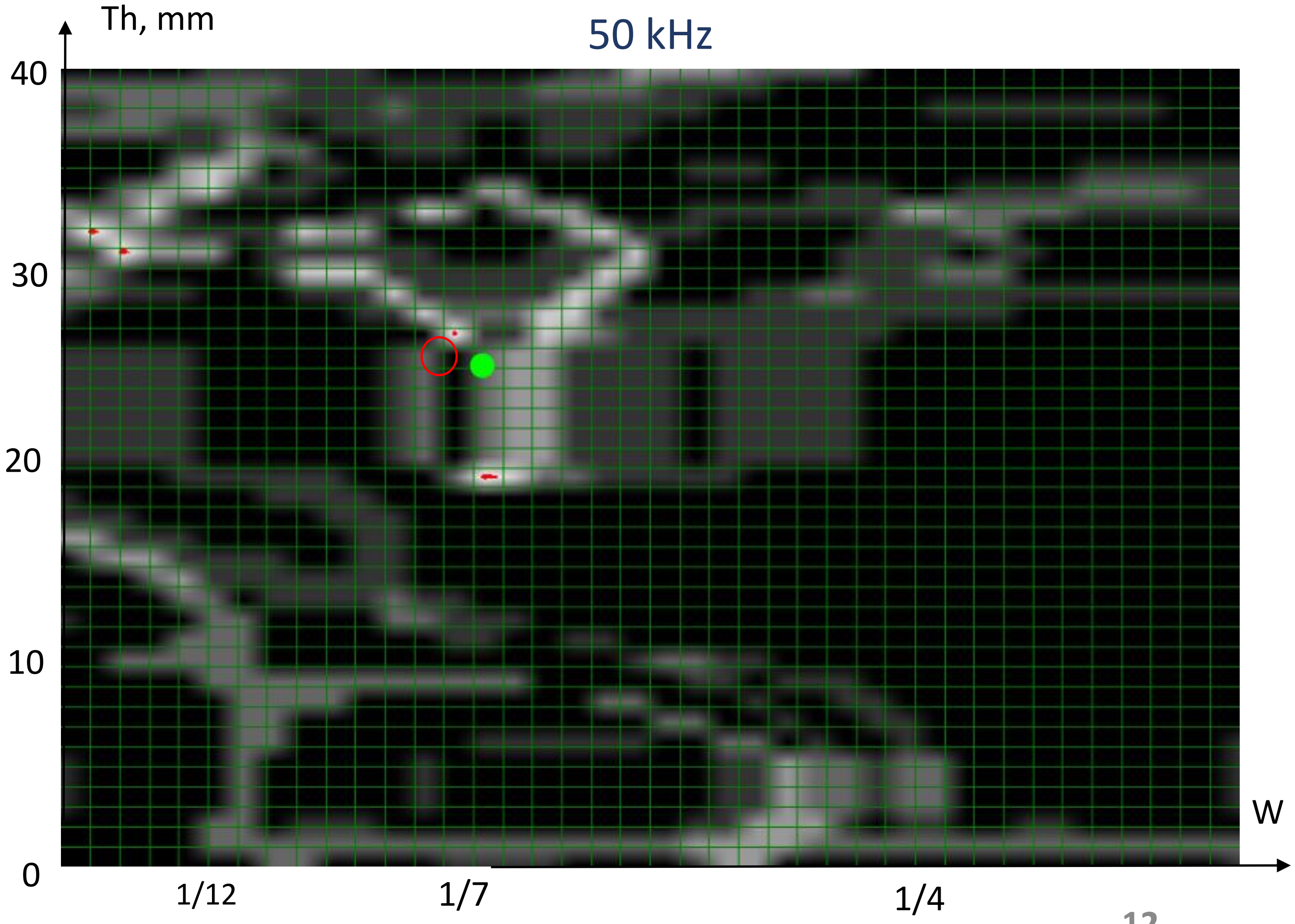
5. Pattern recognition applied to ultrasonic data

5.5.1. Determination of Factors-of-Interest, Case 1: FOI1 Th = 25 mm; FOI2 W = 1/7

Use of criteria at a single ultrasonic frequency

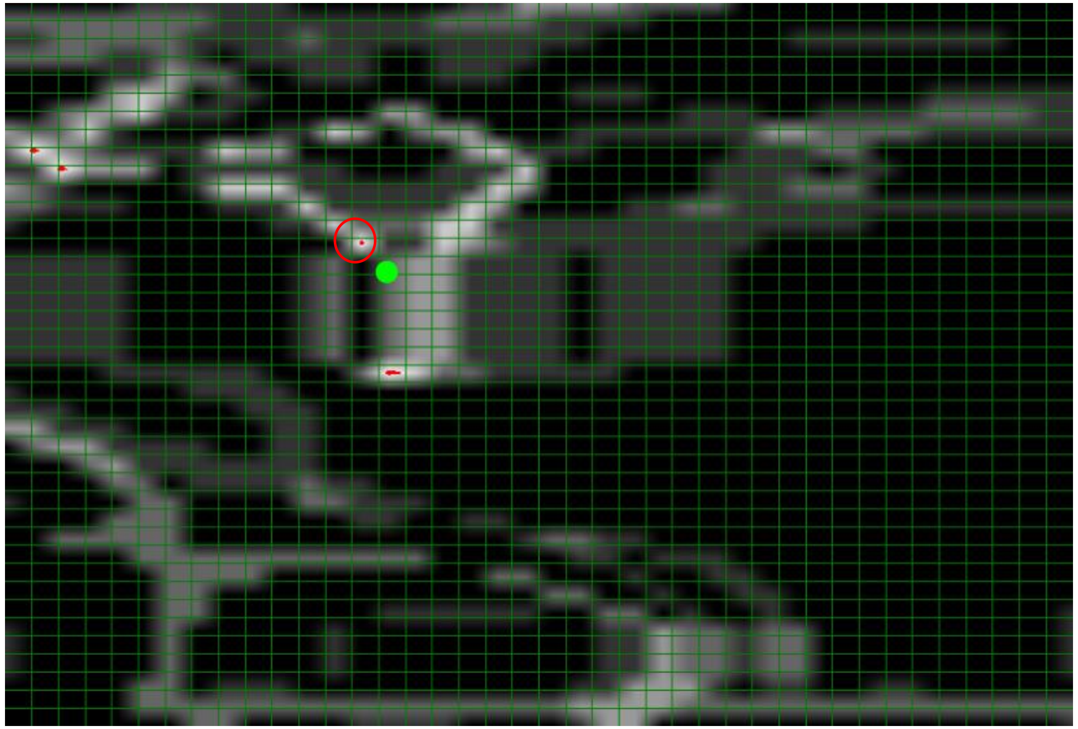




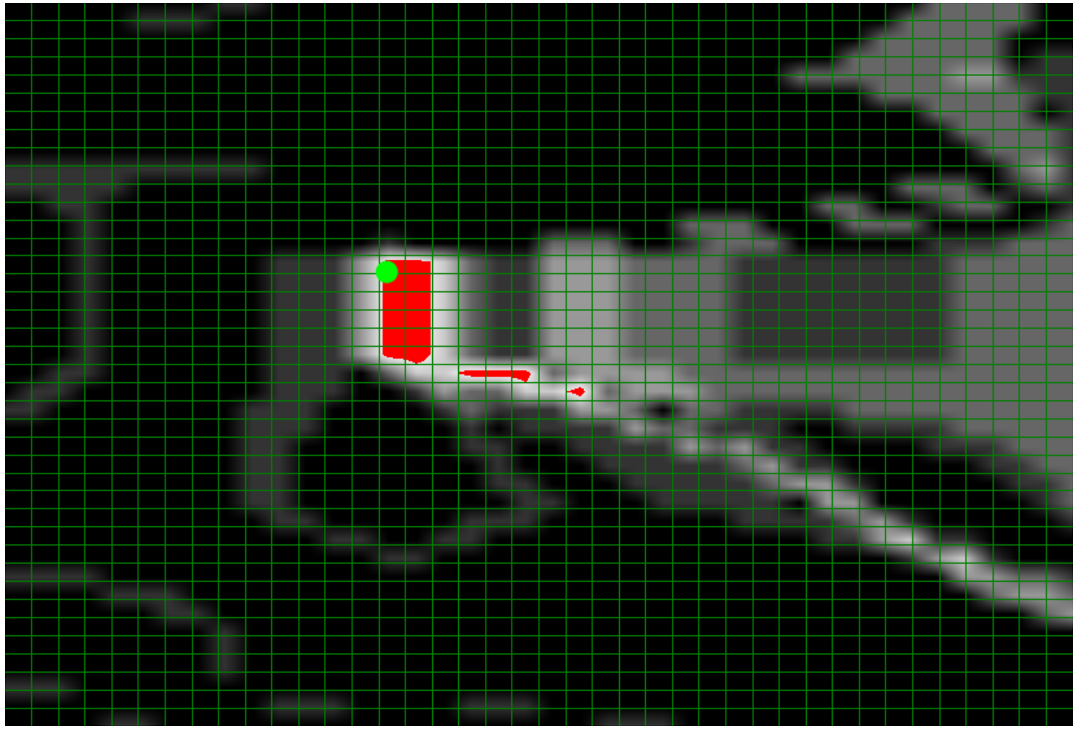
5. Pattern recognition applied to ultrasonic data

5.5.1. Determination of Factors-of-Interest, Case 1: FOI1 = 25 mm; W = 1/7

50 kHz



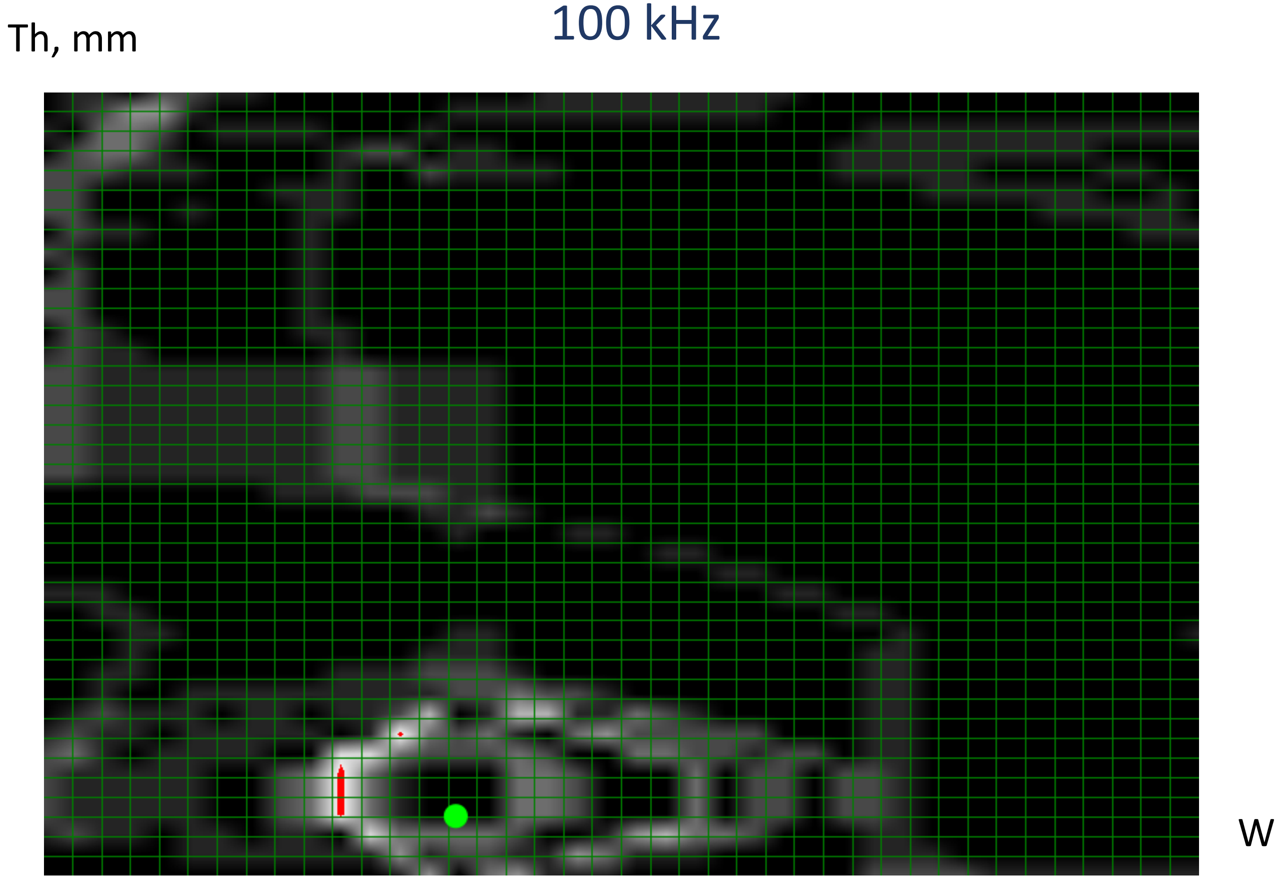
200 kHz



5. Pattern recognition applied to ultrasonic data

5.5.2. Determination of Factors-of-Interest, Case 2 FOI1 Th = 3 mm; FOI2 W = 1/7

100 kHz



6. Conclusions

1) Ultrasonic 2D spatiotemporal profiles formed by surface waves are sensitive to both the depth and the degree of degradation of the surface layer of concrete. The use of mathematical methods for pattern recognition makes it principally possible to differentially evaluate both factors.

2) An adequate choice of decision rules and a proper estimation of its weights in pattern recognition are key elements of correct diagnostics.

Acknowledgement:
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Thank you for attention!

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