ASSESSMENT OF DAMAGE IN ROCK BOLTS USING ULTRASONIC GUIDED WAVE MODE CONVERSION

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Introduction

Rock bolts in underground excavation and civil engineer structure commonly suffer from corrosion and fatigue issues.

Introduction

- Visual inspection does not provide information on the state of the bolt inside the rock mass.
- Non-destructive methods have to be used for a proper diagnosis of the condition of rock bolts

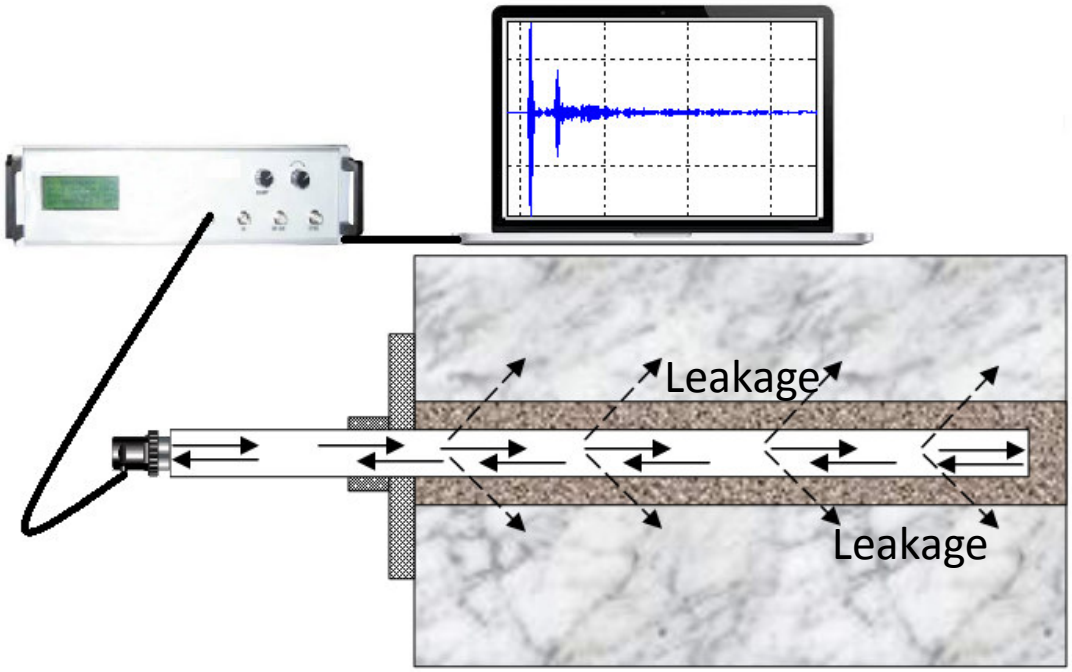
Visual Inspection

Outline

- Background on ultrasonic pulse echo in cylindrical rod.

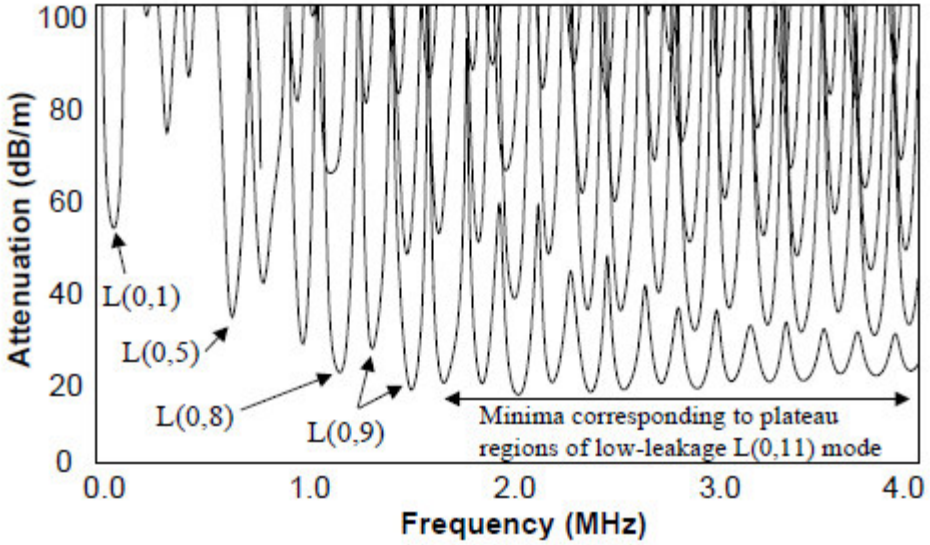
  - Ultrasonic Wave propagation and trailing echoes generation.
- Ultrasonic Transducer selection.
- Tests, data processing and some Results.
- Conclusion

Ultrasonic pulse echo in cylindrical rod



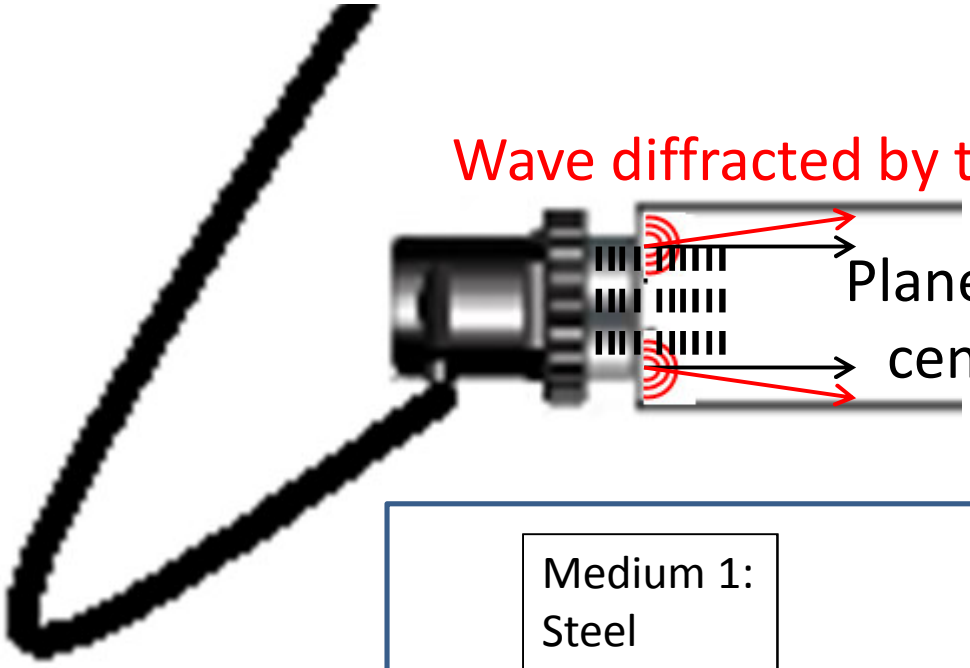
Dispersion

Attenuation disperse curve



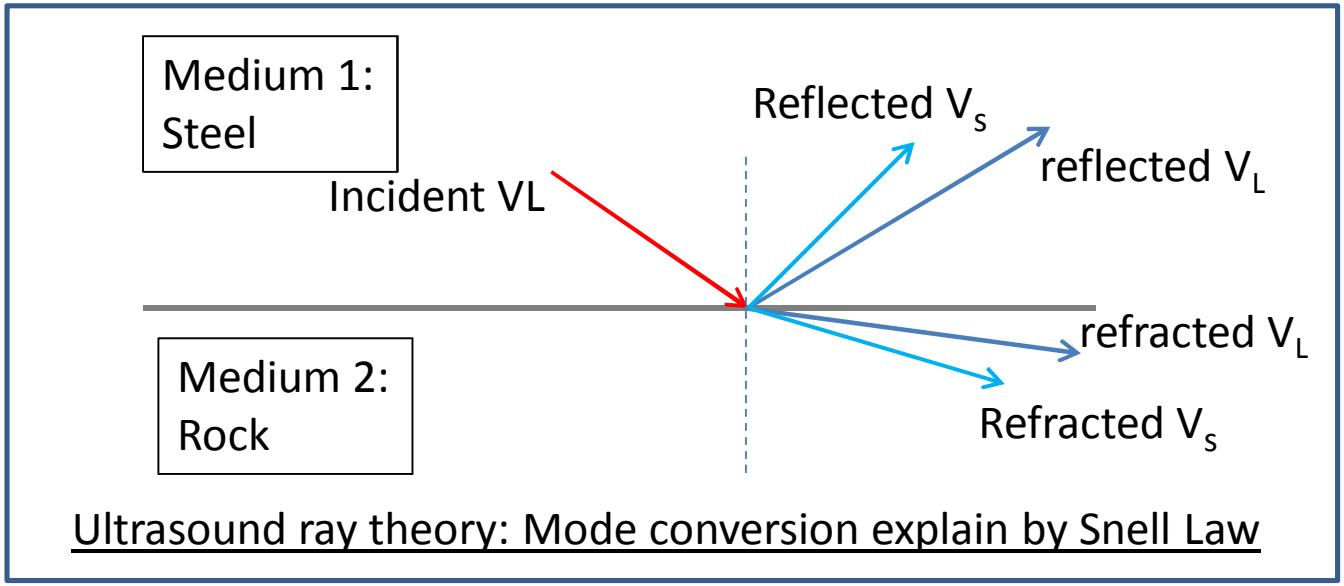
(*M.D. Beard, M.J.S. Lowe, "Non-destructive testing of rock bolts using guided ultrasonic waves" International Journal of Rock Mechanics & Mining Sciences 40 (2003) 527–536*)

Trailing echoes generation



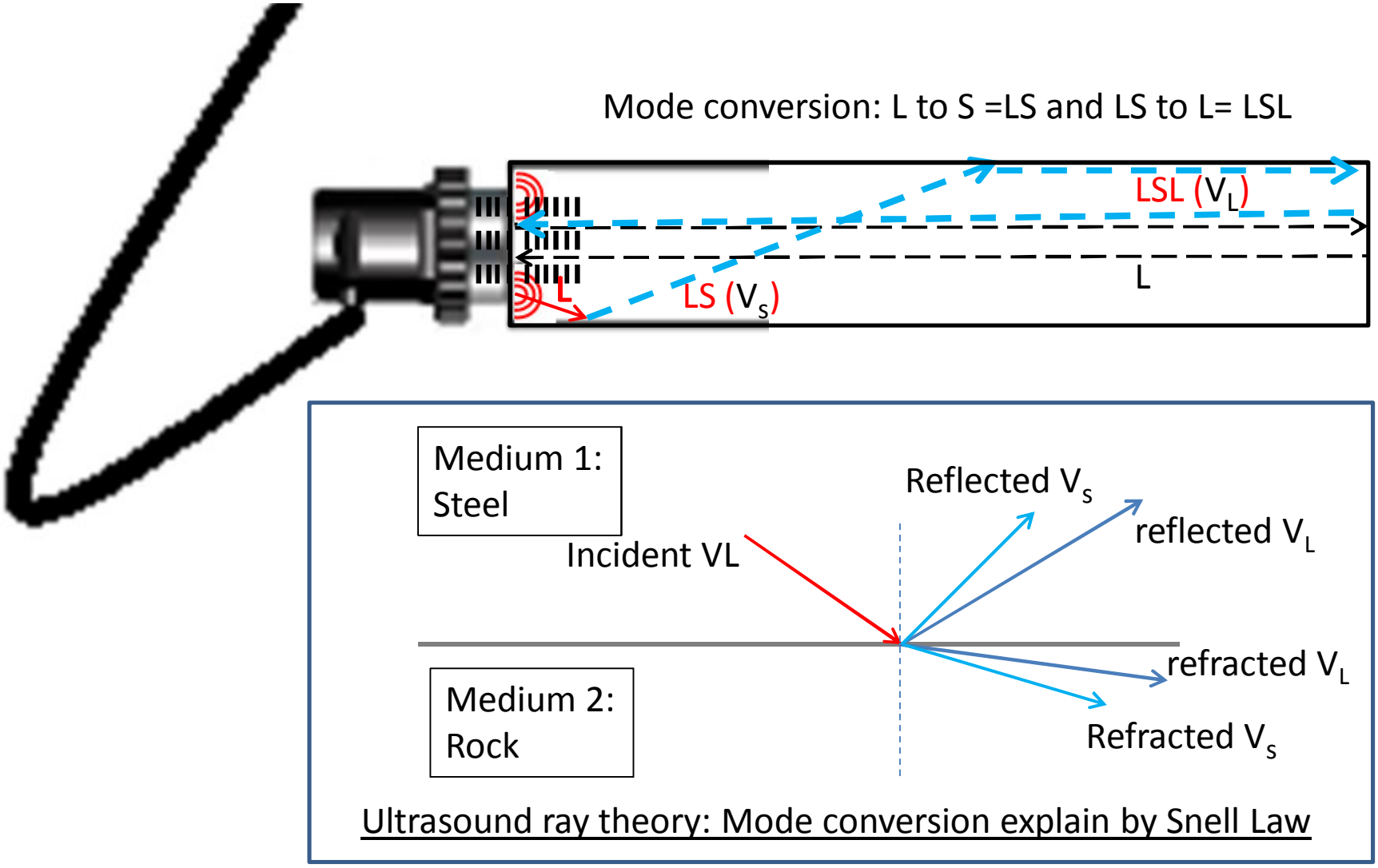
Wave diffracted by the edge of the transducer

Plane wave concentrated in the center of the rod



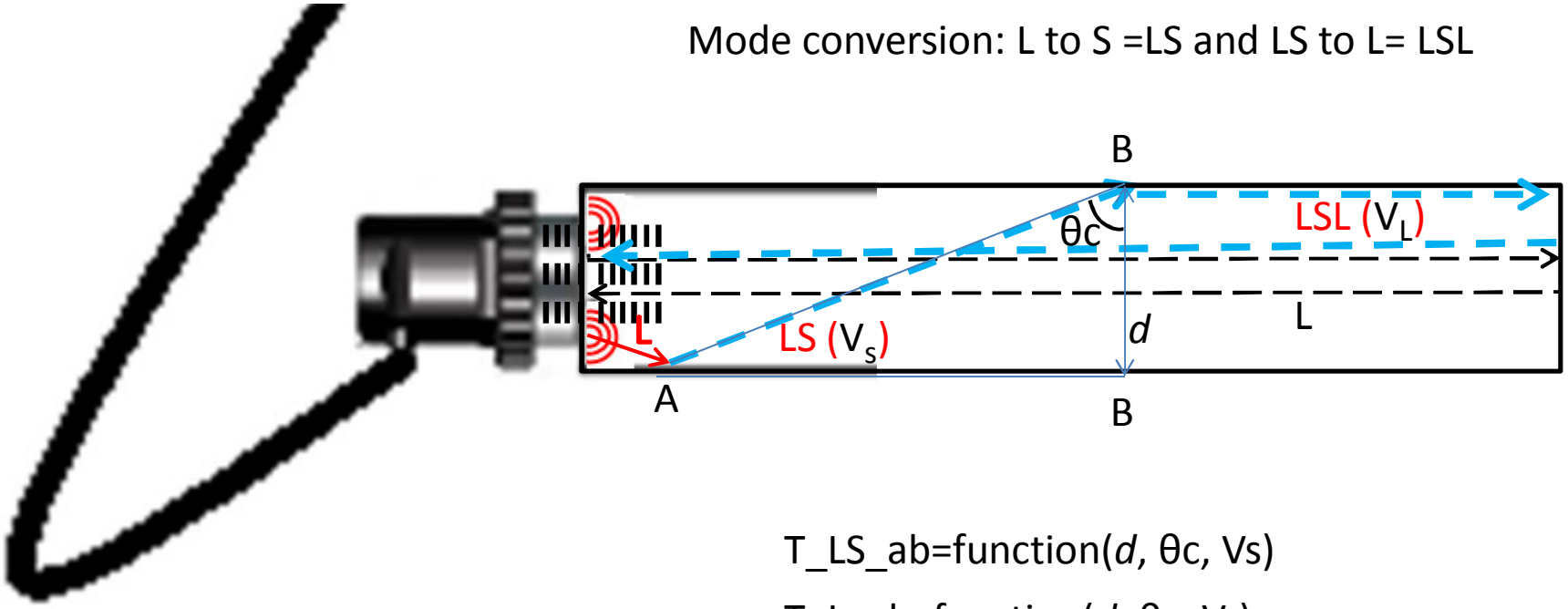
Ultrasound ray theory: Mode conversion explain by Snell Law

Trailing echoes generation



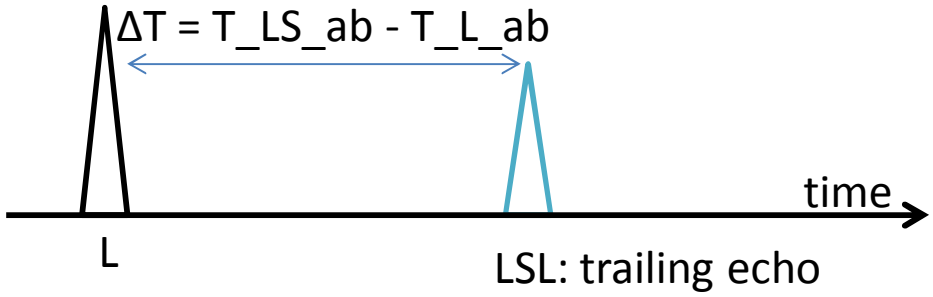
Trailing echoes generation

Mode conversion: L to S =LS and LS to L= LSL



T_LS_ab=function(*d*, θc, Vs)

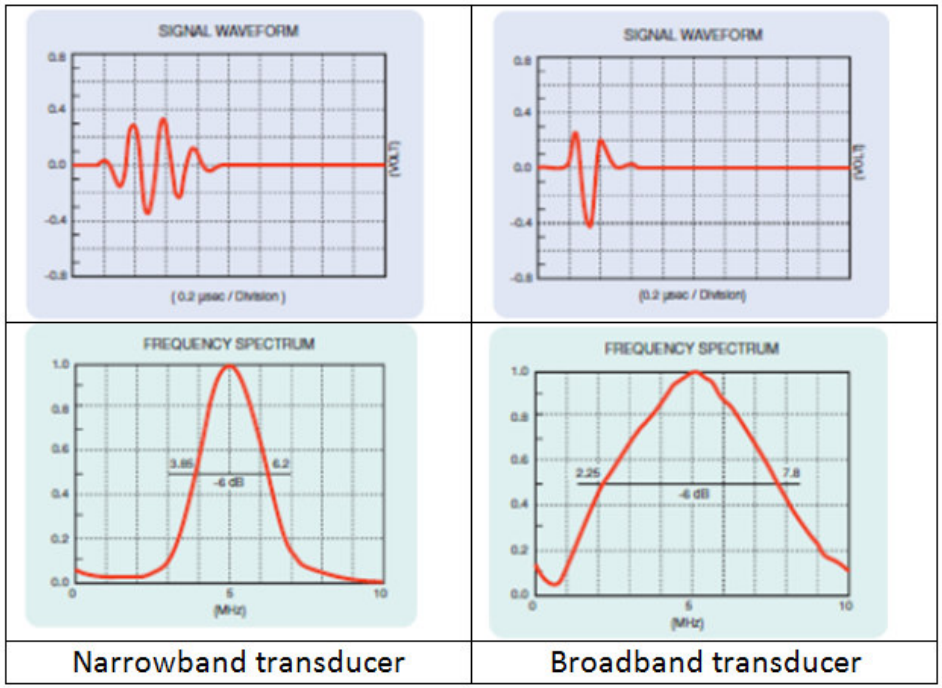
T_L_ab=function(*d*, θc, V_L)



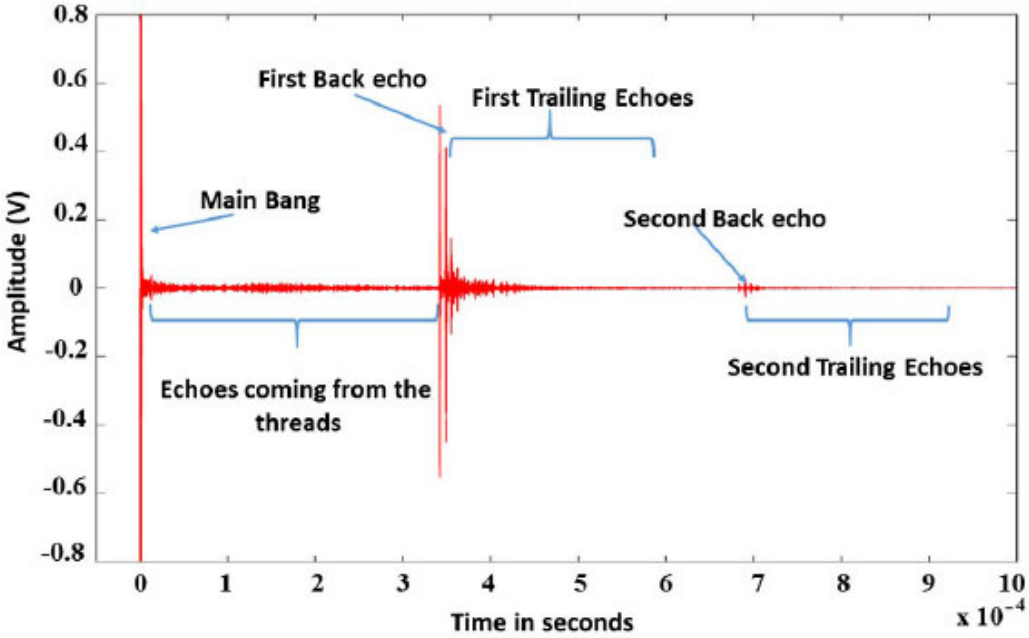
$$\Delta T = \frac{d\sqrt{V_L^2 - V_S^2}}{V_L V_S}$$

Ultrasonic Transducer selection

- Avoid interference →Narrowband transducer
- Reduce leakage → Central Frequency : wavelengh very short than the rock bolt diameter
- Transducer diameter : 0,75 po (19 mm).

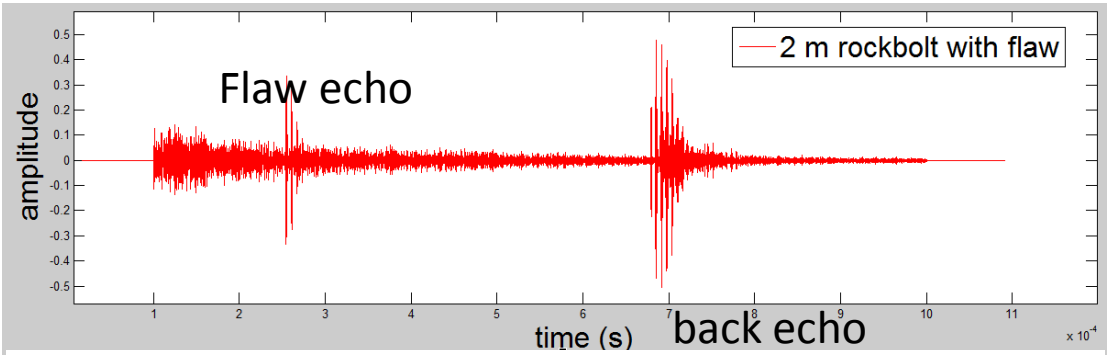


Tests, data processing and Results



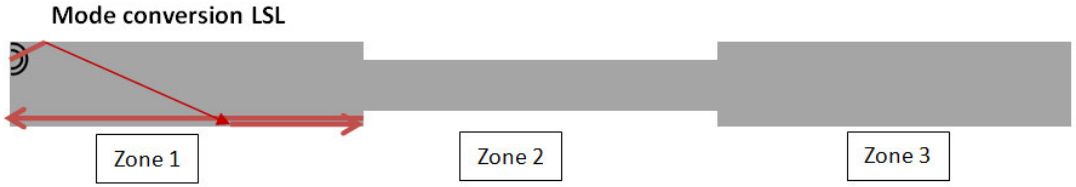
Typical pulse echo signal

Tests and Results

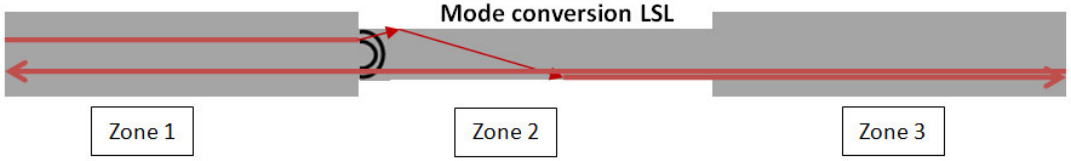


$$\Delta T = \frac{d\sqrt{V_L^2 - V_S^2}}{V_L V_S}$$

V_L= 5900 m/s
V_S= 3180 m/s

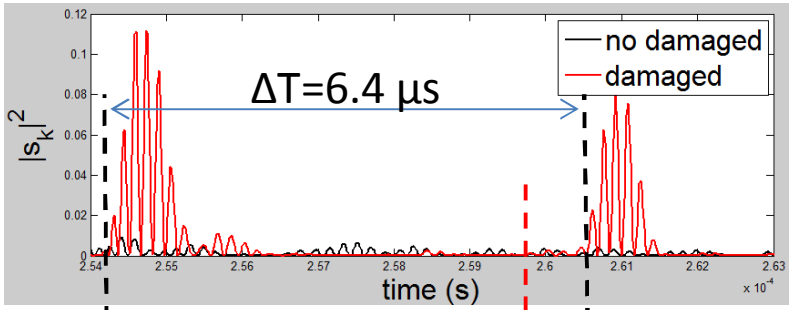


Zone 1: d=25 mm ((measured with vernier caliper) d=24 mm (estimated by US pulse echo)

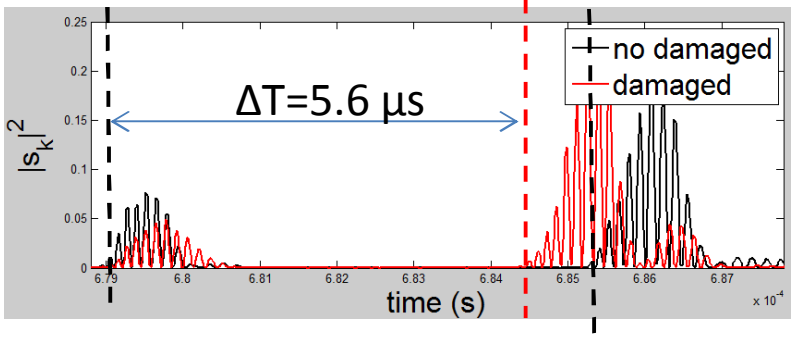


Zone 2: d=21 mm (measured with vernier caliper) d=21 mm (estimated by US pulse echo)

Flaw echo

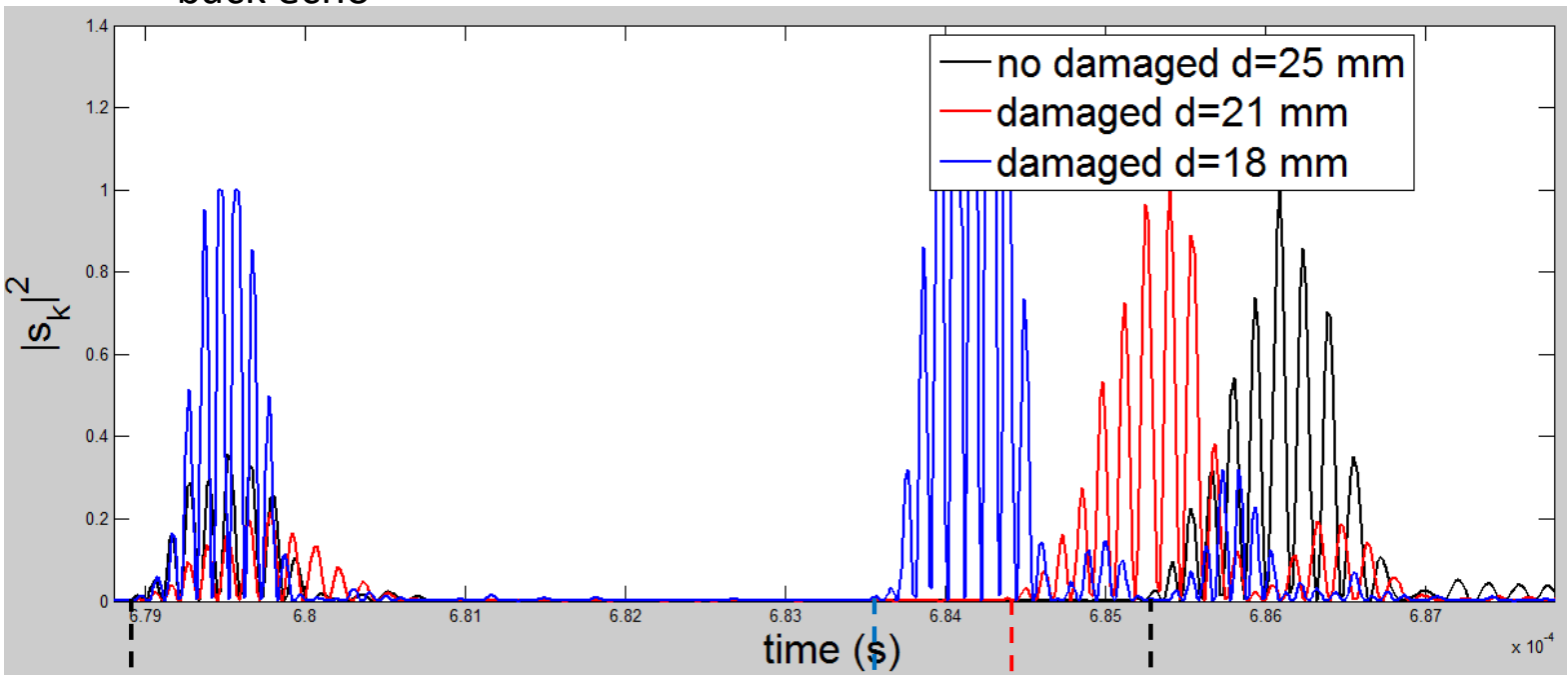


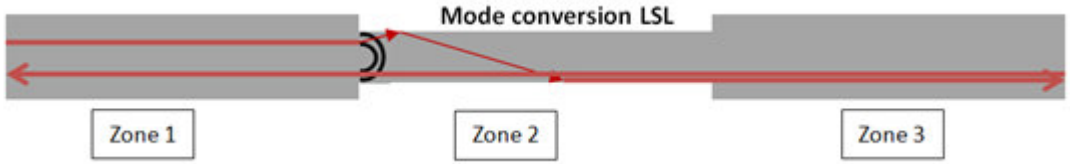
back echo



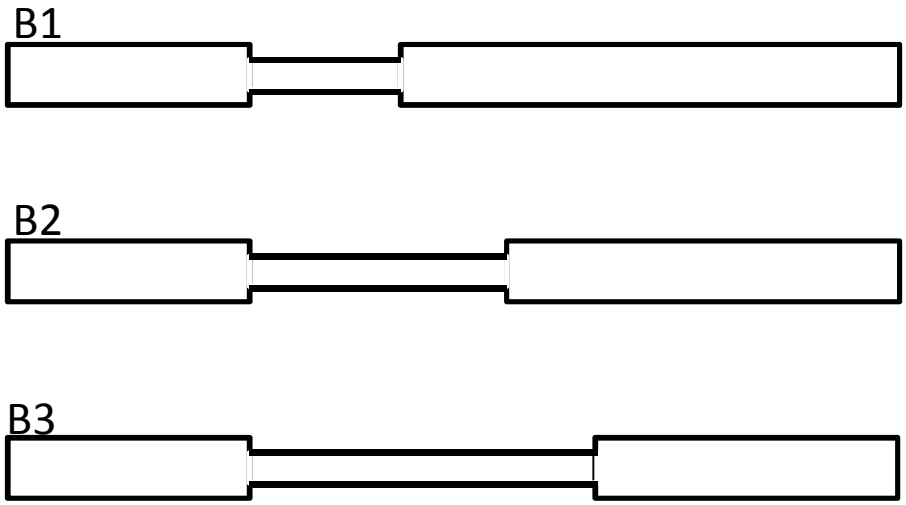
Tests and Results

back echo



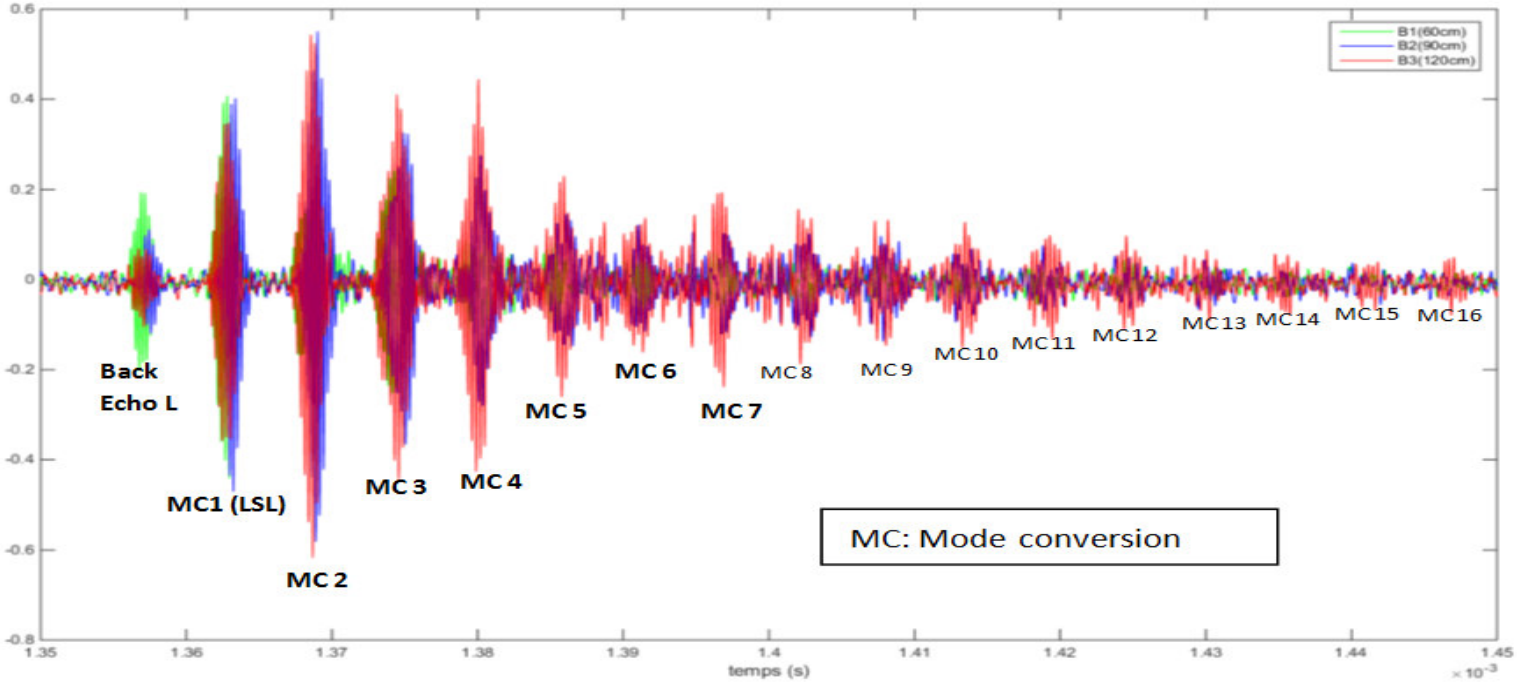


Tests, data processing and Results



Rock bolts	d0 (mm)	d1 (mm)	l (m)	l_flaw (mm)
B1	25	21	3.5	60
B2	25	21	3.5	60
B3	25	21	3.5	60
reference	25	no flaw	3.5	no flaw

Tests, data processing and Results



V_S , V_L measured from the flaw reflection

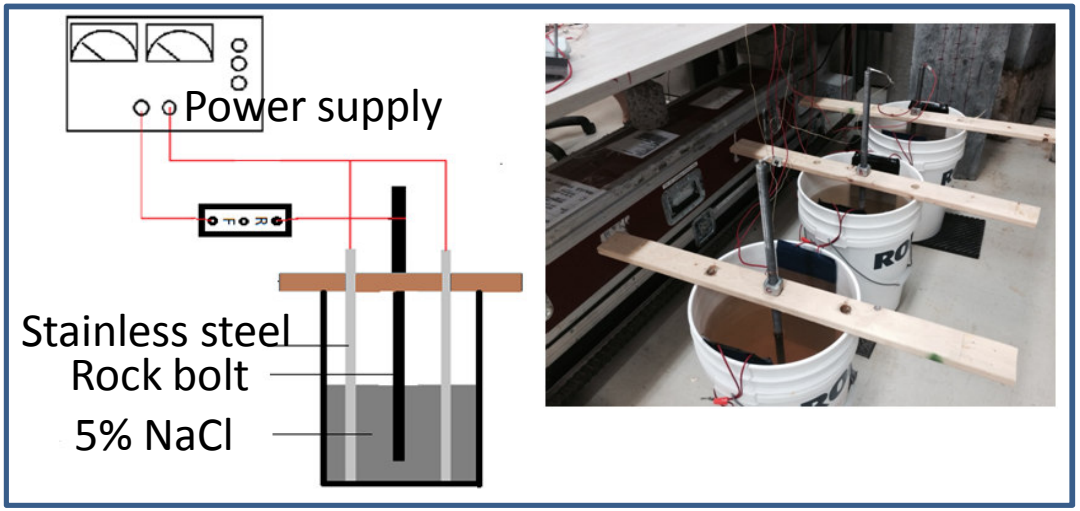
Rock bolts	V_S (m/s)	V_L (m/s)	Estimated value d (mm)
B1	3330	5899	22
B2	3290	5899	21
B3	3400	5903	21

Measured value d= 21 mm.

V_S , V_L from average of 6 rock bolts V_S , V_L

Rock bolts	V_S (m/s)	V_L (m/s)	Estimated value d (mm)
B1	3304	5899	22
B2			21
B3			21
reference			25

Tests and Results



Uniform corrosion

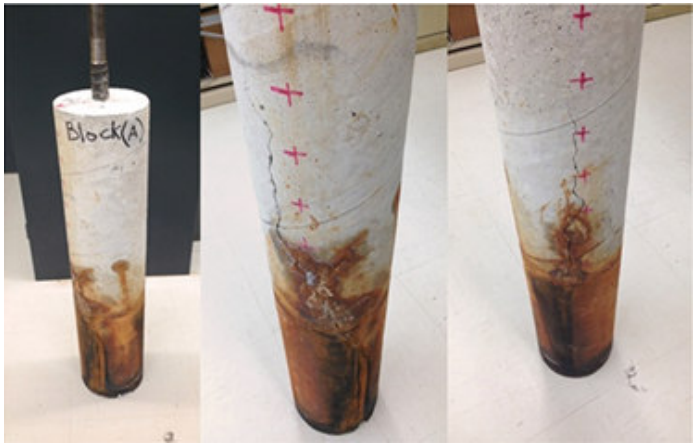
Evaluation of section loss during accelerated corrosion process

Number of days	Estimated diameter (by pulse echo) (mm)	Measured diameter (mm)
Day 0 (0H)	25	25
Day1 (24h)	24.5	-
Day2 (48H)	24.5	-
Day3 (96H)	21	20
Day4 (144H)	9,8-17	4,3-16

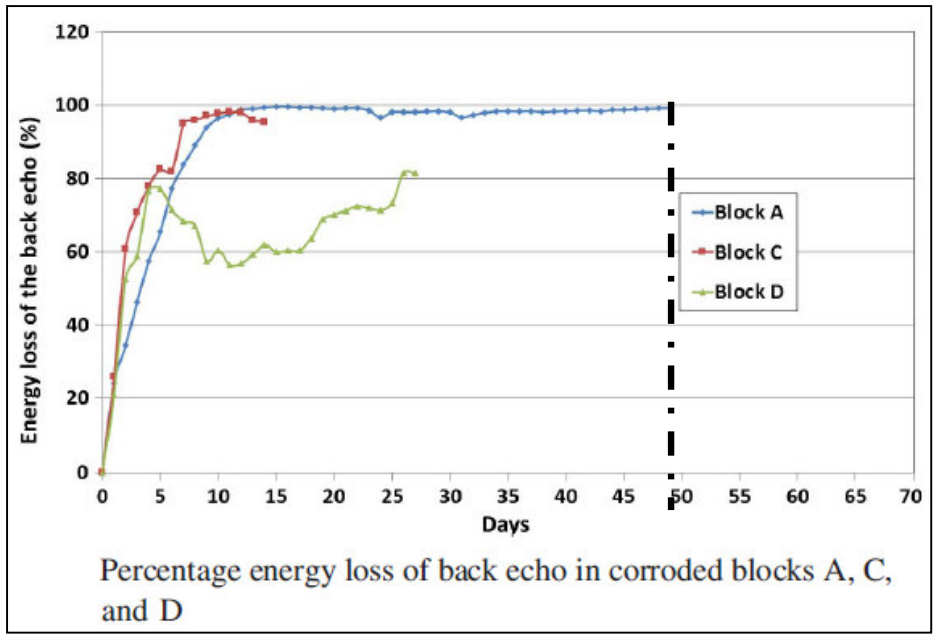
Tests, data processing and Results

3 Blocks A, C, D submitted to accelerated corrosion

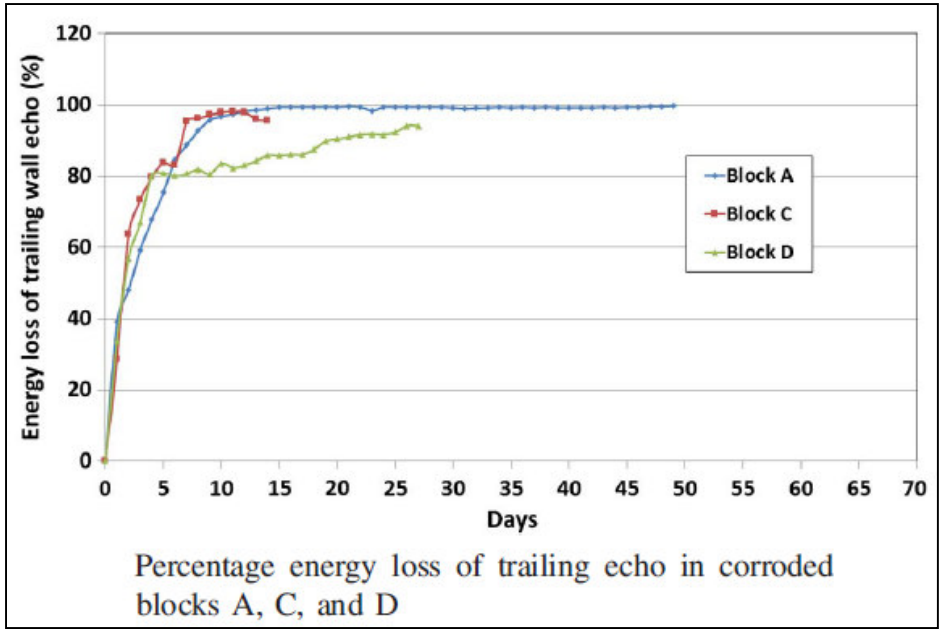
Length rock bolt =1 m



Pulse echo energy loss during corrosion process

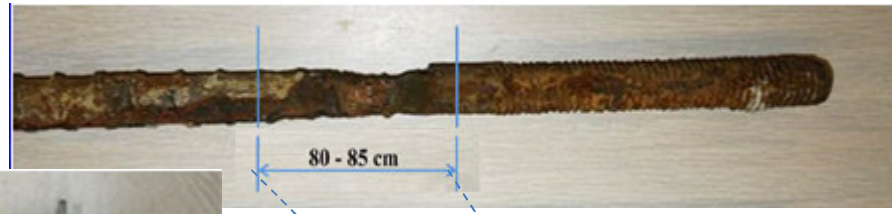


Percentage energy loss of back echo in corroded blocks A, C, and D



Percentage energy loss of trailing echo in corroded blocks A, C, and D

Tests, data processing and Results

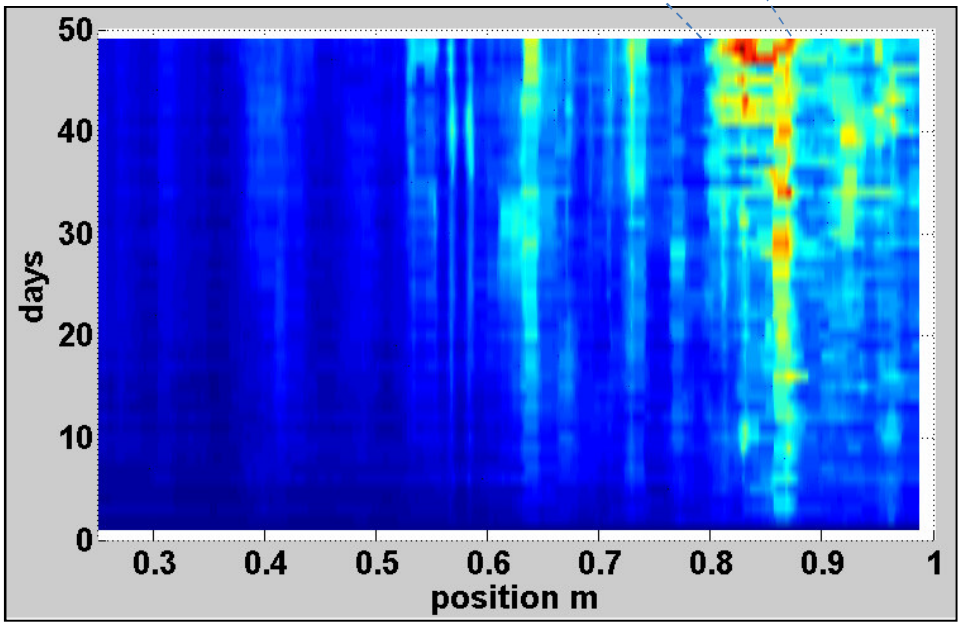


Transducer Attachment

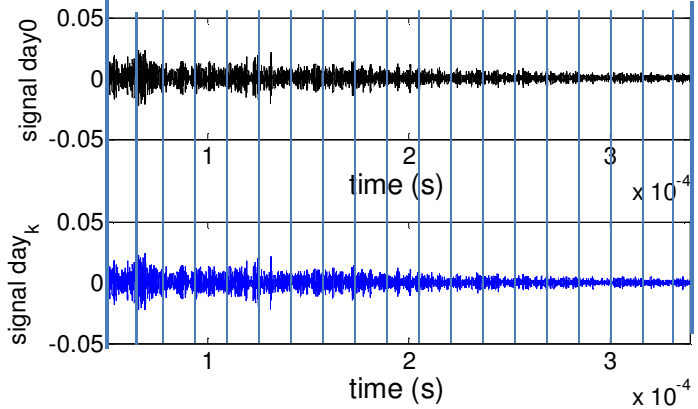
Cross correlation function

$$CC_{S_{unp}S_{prt}}(\tau) = \frac{\int_{t-t_w}^{t+t_w} S_{unp}(t')S_{prt}(t'-\tau)dt'}{\sqrt{\int_{t-t_w}^{t+t_w} S_{unp}^2(t').S_{prt}^2(t')dt'}}$$

Position = (velocity x time)/2

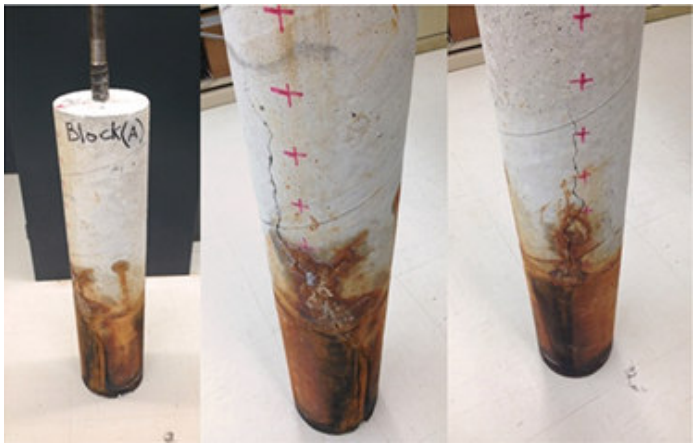


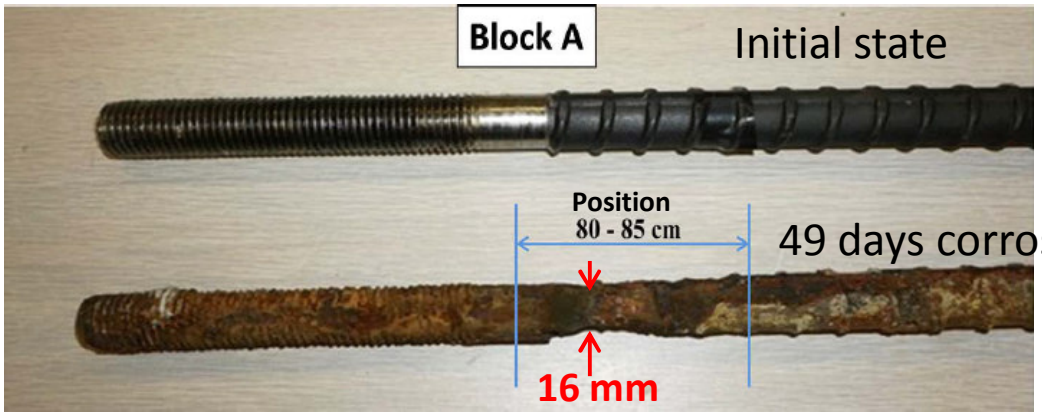
Mesh of Matrix [position$_i$, day$_k$, |max(CC)|$_{i,k}$]

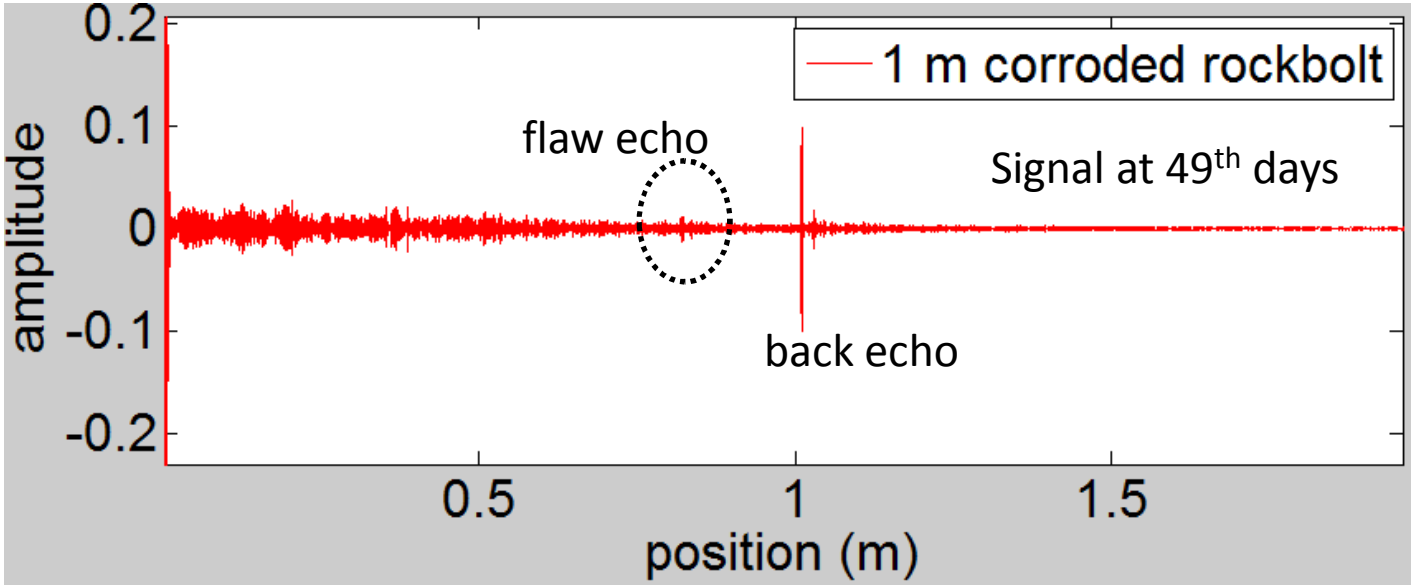


Part of signal before back echo

Localization of the flaw position

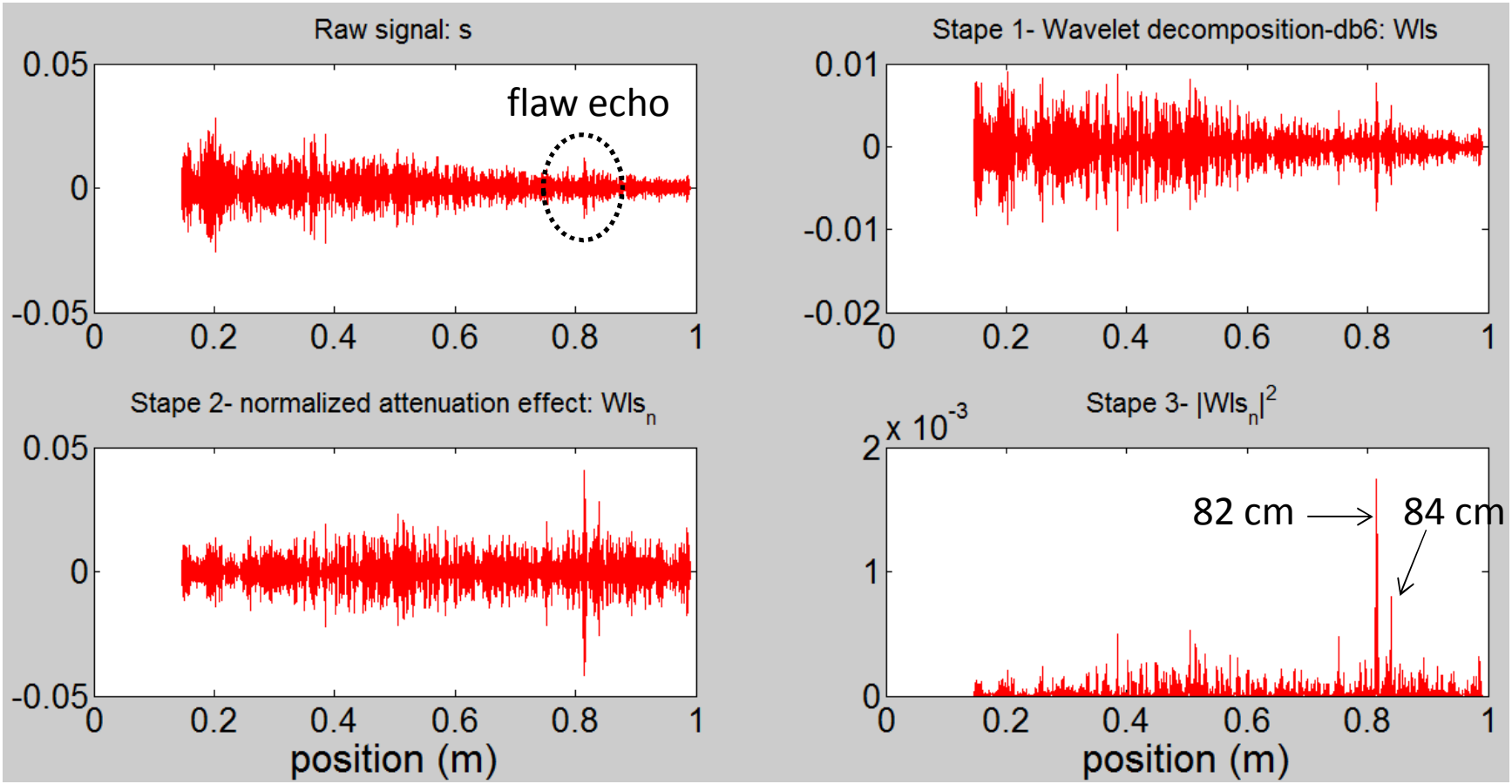






Tests, data processing and Results

Localization of the flaw position



Conclusions

- The relevance of Pulse echo technique
  - to evaluate integrity of rock bolts
  - To detect flaw and its position
- Trailing echo delay allowed estimated rock bolt section loss.
- However trailing echo cannot estimate crack or pitting corrosion depth.
- Alternative technique is under development using flaw echo energy.

Thank You !

Questions ?

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