

# Real-Time Bridge Scour Monitoring: Recent Technological Development



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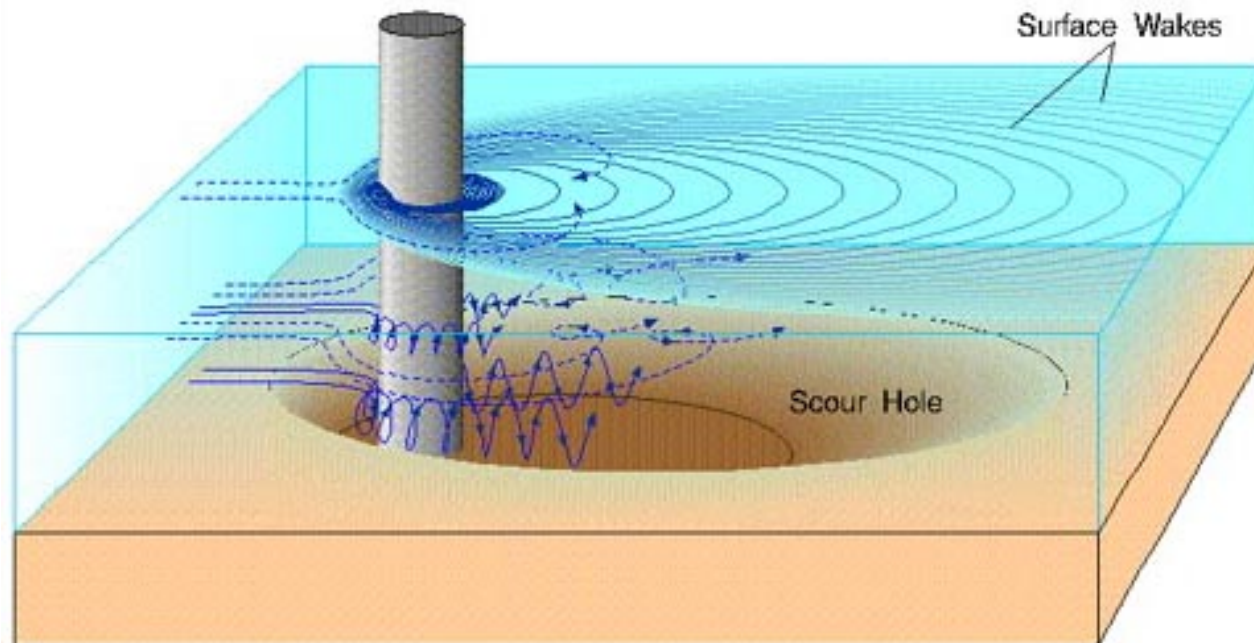
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# Background

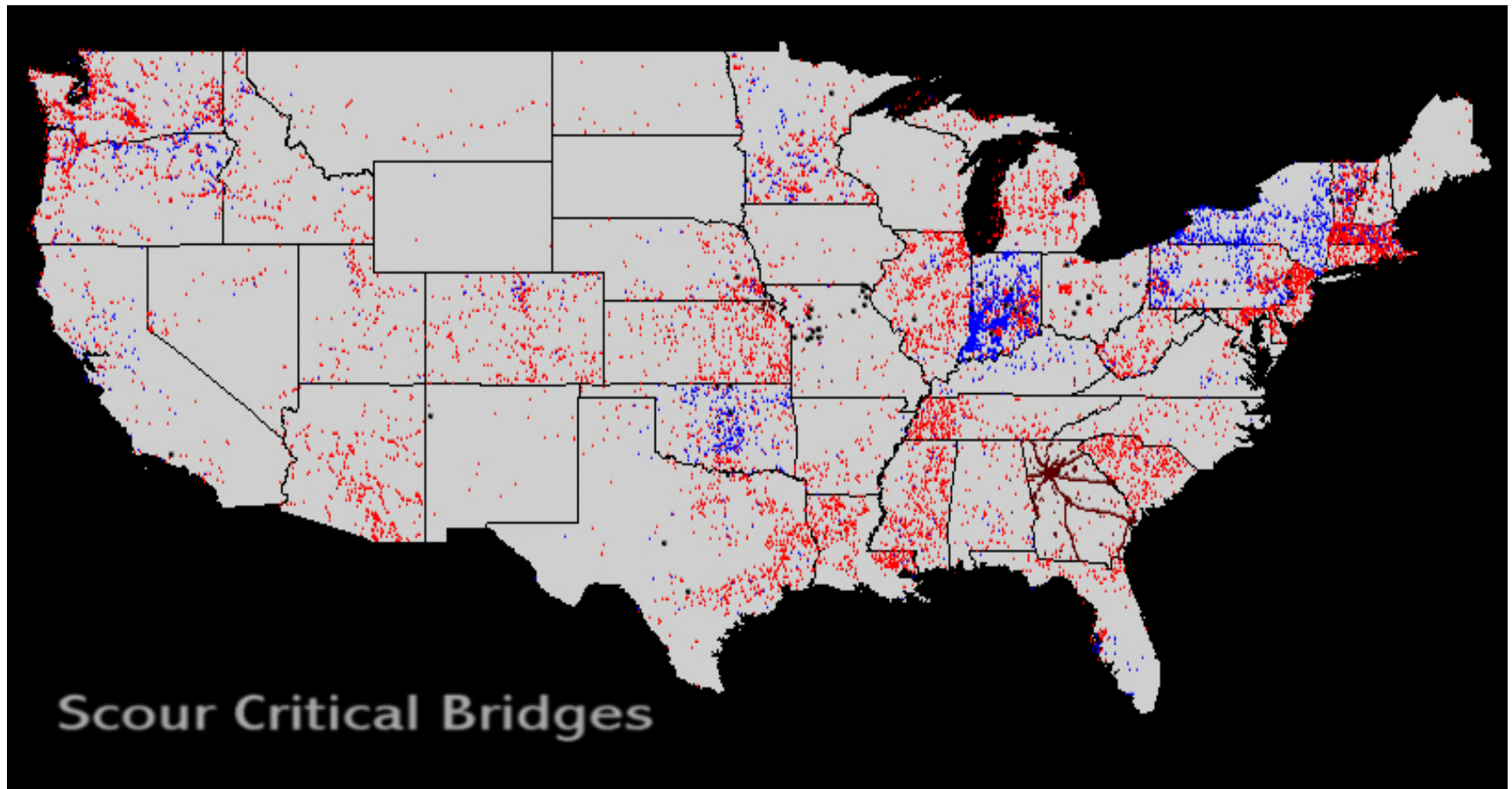
- Scour
  - the lowering of streambed around bridge piers or abutments
- Types of scour
  - long-term degradation of the river bed
  - general scour
  - local scour at the piers or abutments

Horseshoe and Wake Vortices around a Cylindrical Element



# Background

- ❑ Scour of pier or abutment poses a most severe threat to bridge service life
- ❑ 503,000 bridges traverse waterways, over 20,000 are classified as scour critical
- ❑ 1000 bridges have collapsed in 30 years in the USA and scour was responsible for 60% of those failures



# Scour Caused Bridge Collapse

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I-90 bridge collapse on Schoharie Creek, April 5, 1987.  
Courtesy of Sid Brown, Schenectady Gazette.

# Purpose of Study

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- ❑ Current scour design specifications are based models from laboratory data. They generally doesn't adequately describe the field condition.
- ❑ Instrument of bridge scour in the field helps:
  - Calibrate and refine the numerical models for sediment movement and bridge scour;
  - Describe the trend of scour evolution to help scheduling the remediate measure;
  - Real-time warning to prevent human or property loss due to catastrophic failure.
- ❑ This study investigates the application of electromagnetic wave technology (TDR) monitoring of scour/sedimentation process. Performance is compared with the ultrasonic technology.

# Current Practice for Scour Evaluation

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- ❑ Yard sticking
- ❑ Sounding rod
- ❑ Sonic device
- ❑ Fisher bulb
- ❑ Maximum scour recorder



It is fun, isn't it?

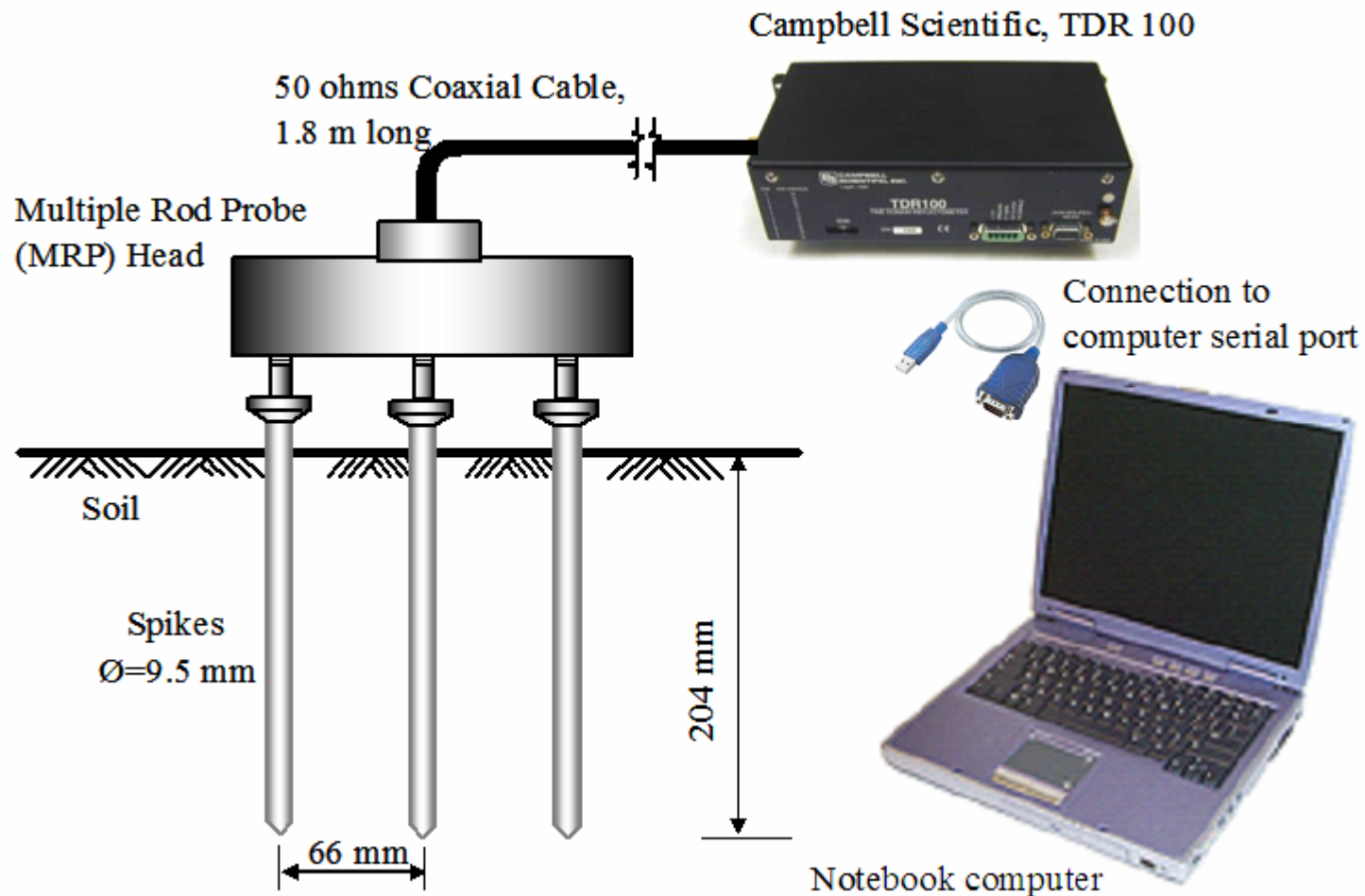
## Current Practice for Scour Evaluation

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- ❑ Most not sufficiently rugged for field use
- ❑ Do not provide real time monitoring
- ❑ Not automatic data collection and interpretation

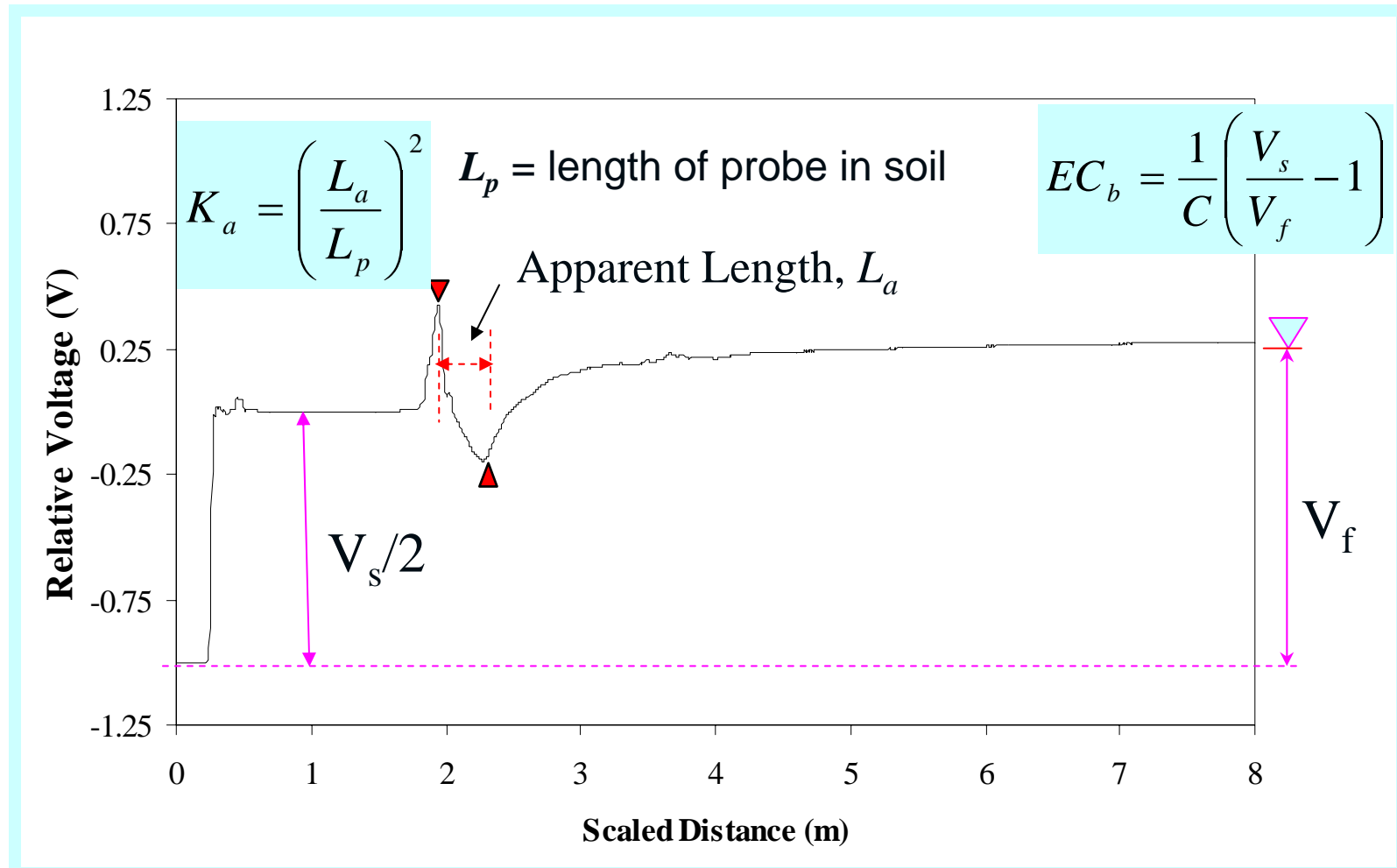
# TDR Background

- Use guided “radar” to identify materials properties and interfaces.
- Involves fast rising EM pulse of picoseconds to accurately determine the interfaces



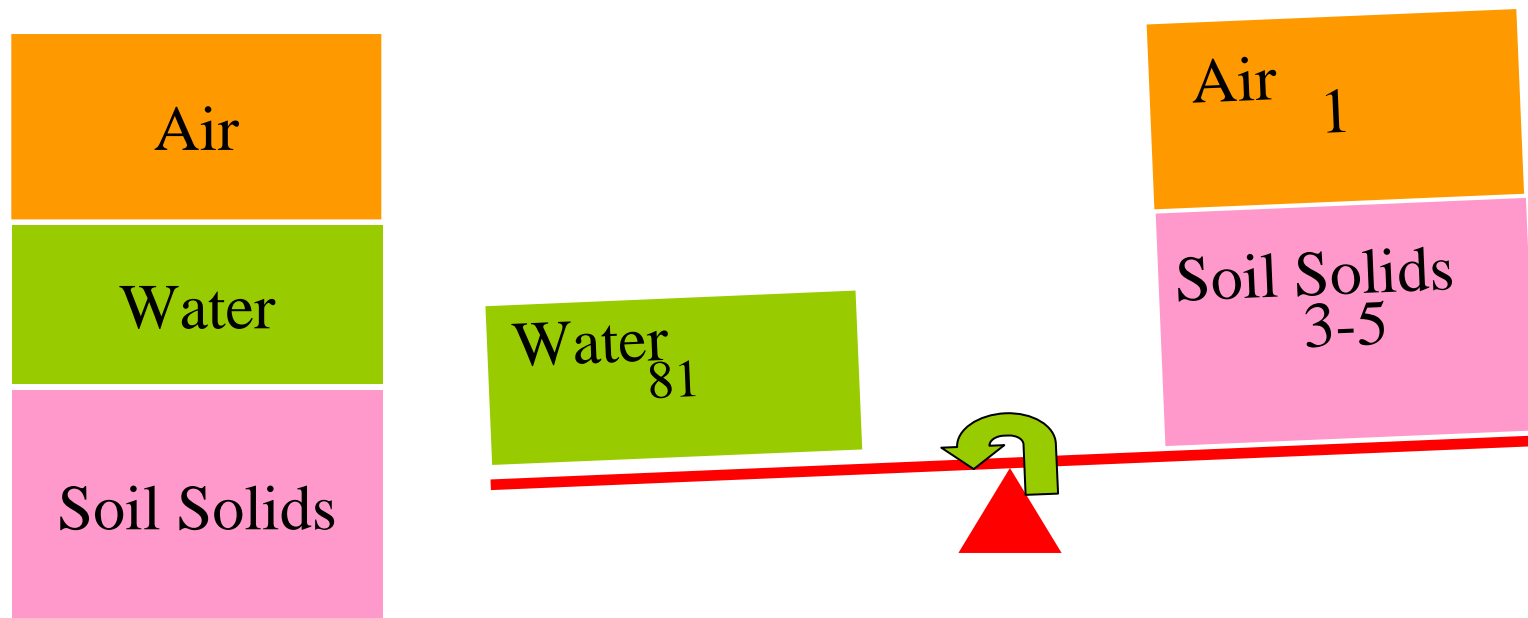
# Information from TDR signal

- Dielectric constant and electrical conductivity



# Soil Dielectric Constant, $K_a$

- Soil dielectric constant,  $K_a \Leftrightarrow$  Young's modulus,  $E$
- Predominantly decided by water content
- Topp's equation relates  $K_a$  to volumetric water content



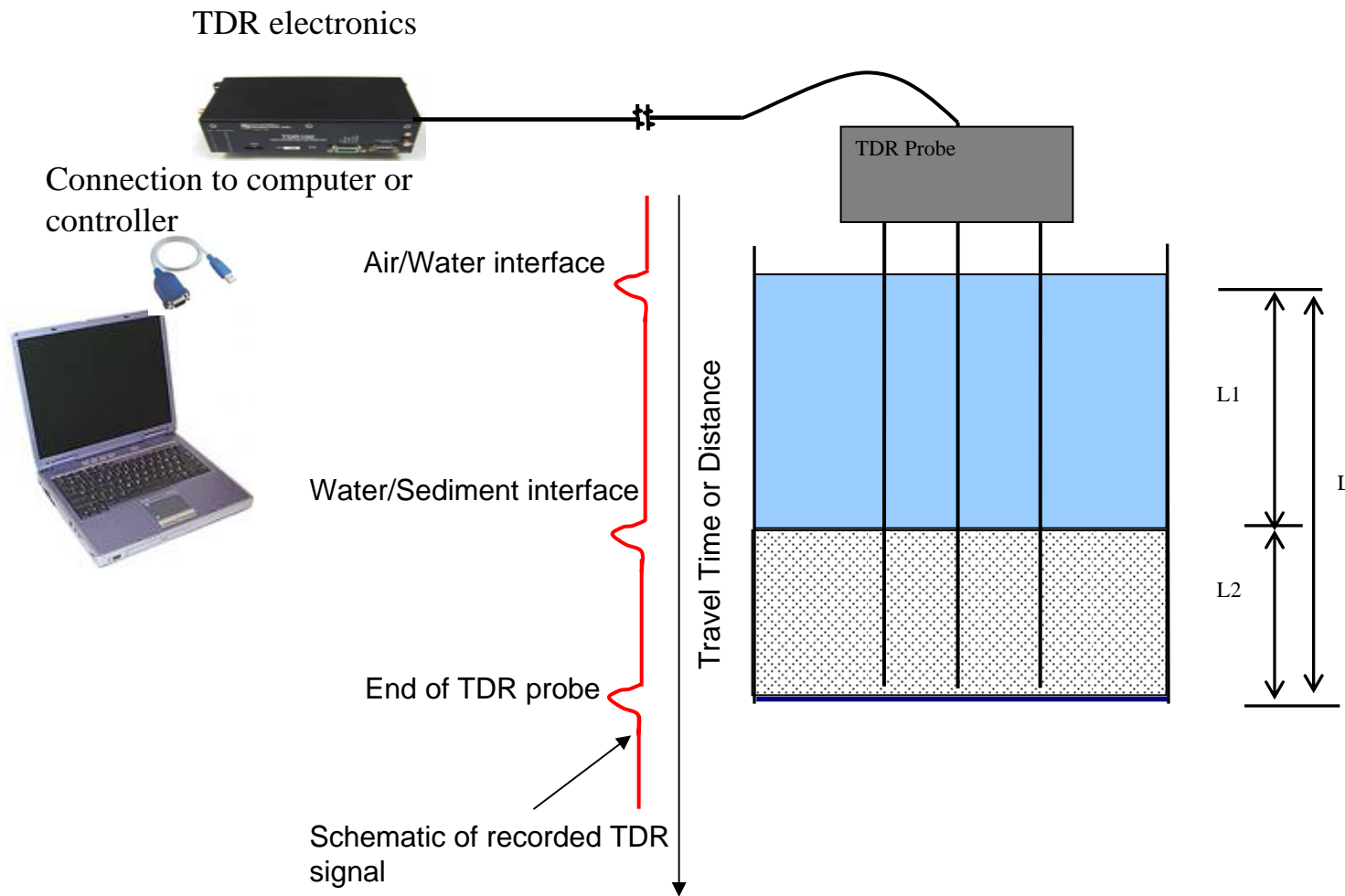
# Reflection at Interface

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$$\rho = \frac{\sqrt{Z_2} - \sqrt{Z_1}}{\sqrt{Z_2} + \sqrt{Z_1}} = \frac{\sqrt{K_{a,1}} - \sqrt{K_{a,2}}}{\sqrt{K_{a,1}} + \sqrt{K_{a,2}}}$$

- Air,  $K_a=1$
- Saturated soil,  $K_a=20\sim40$  depending on density
- Water,  $K_a=81$

# Schema of TDR for scour measurement



# Experiment Setup and Procedure

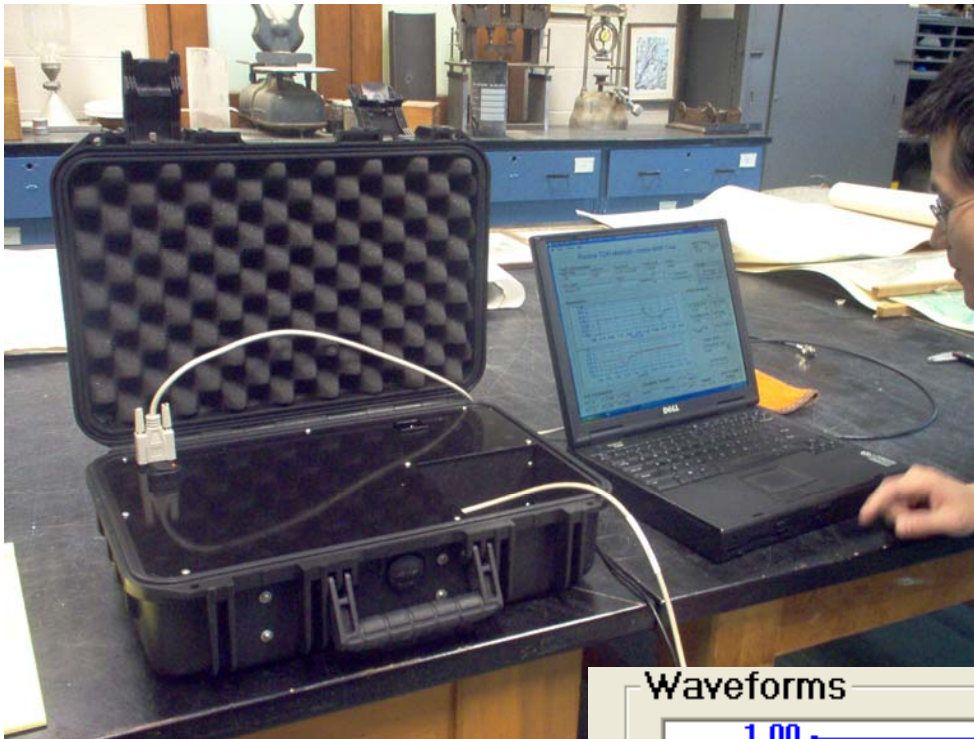
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- ❑ Sand deposit gradually added with the water content kept constant
- ❑ Reflections can be determined

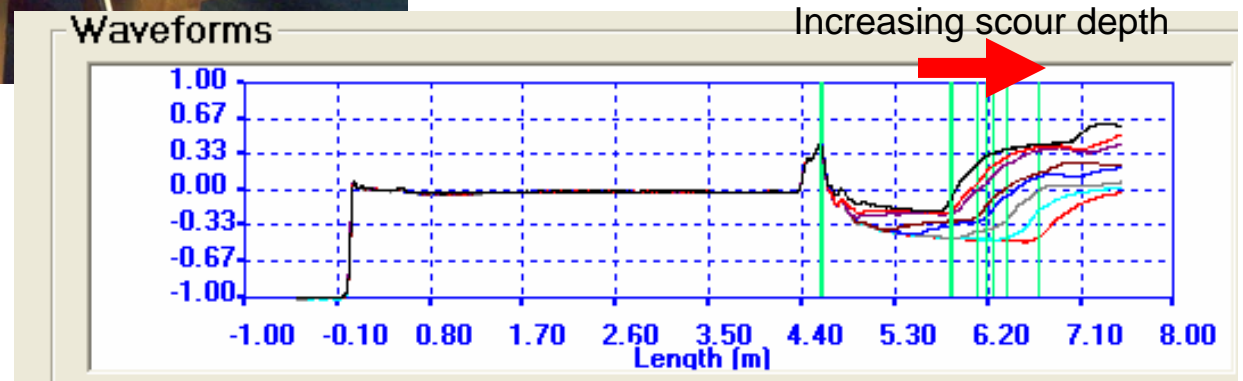


# Data Acquisition

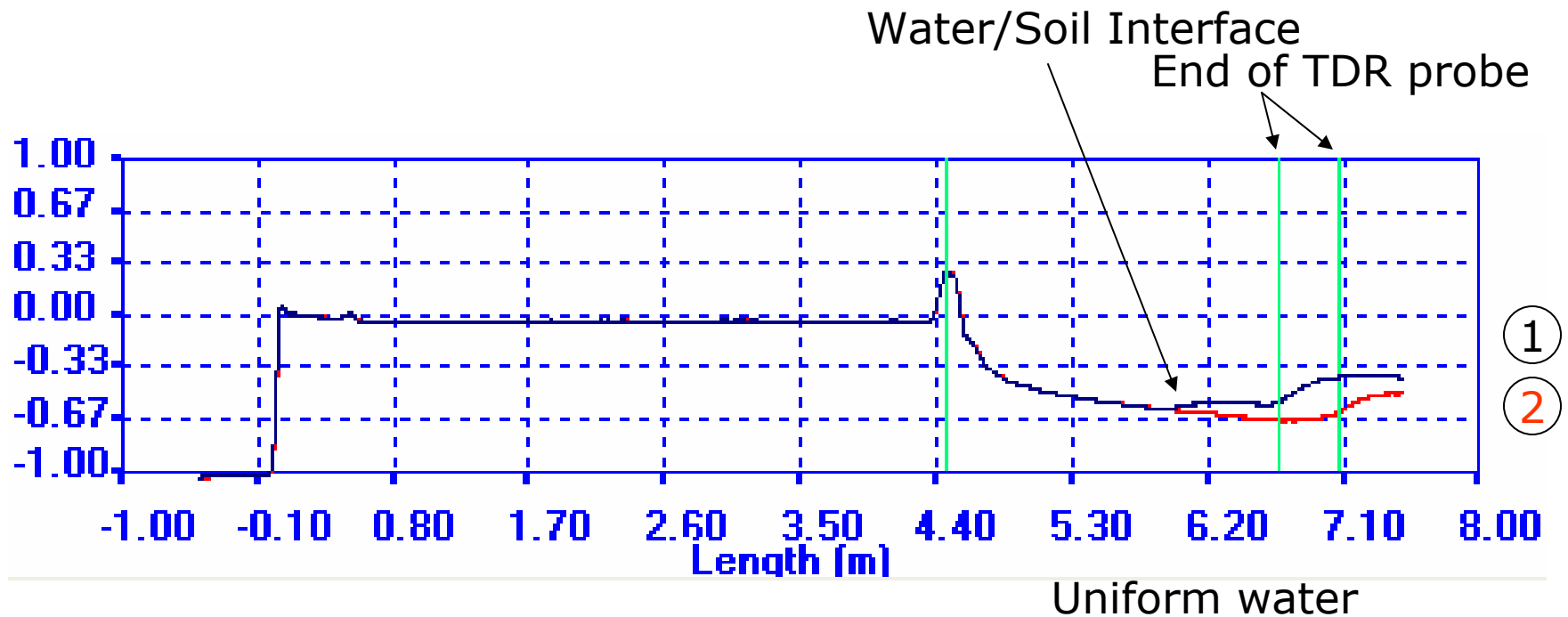
- Computation software was developed to automate signal acquisition and analyses



Measured evolution of signals with sedimentation accumulation



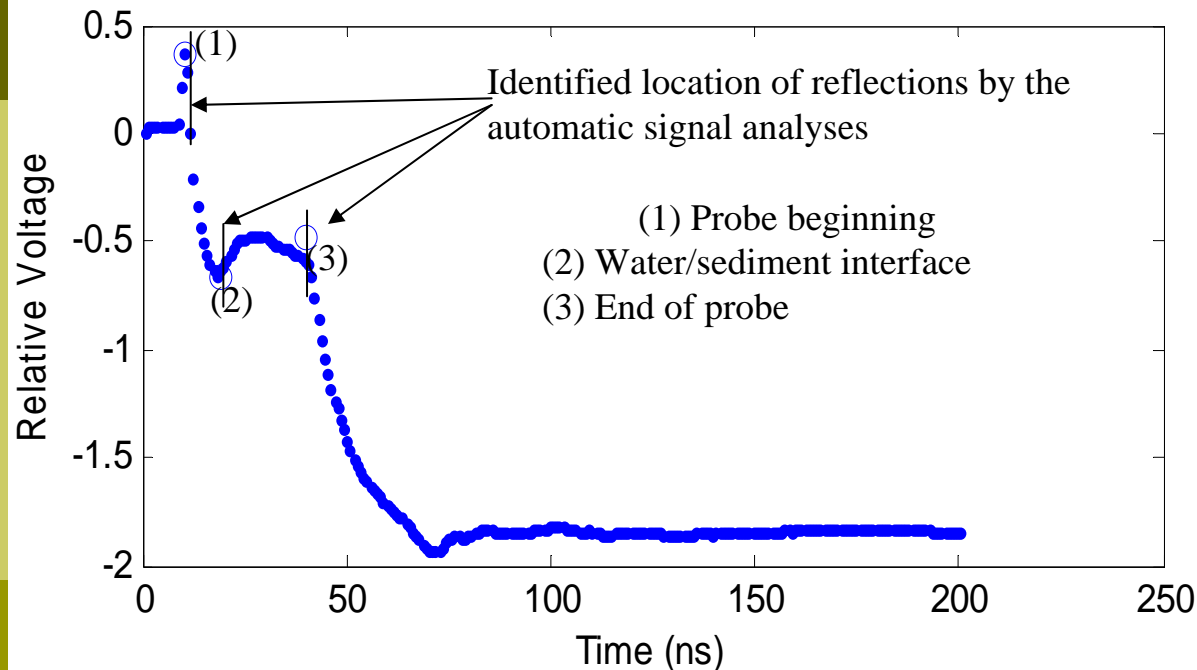
# Typical TDR Signals



- ① TDR signal in soil deposit inundated by water
- ② TDR signal in water

# Signal analyses

## Method 1: Determine internal reflections



$$L_1 = \frac{L_{a,1}}{\sqrt{\epsilon_w}}$$

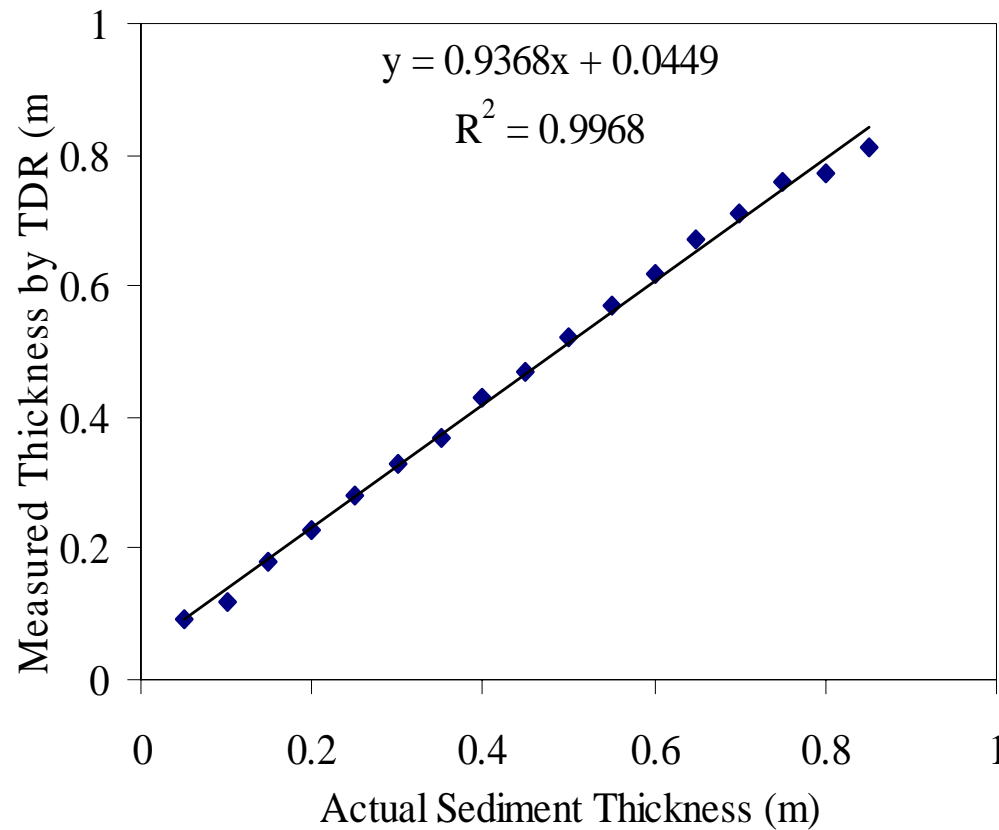
$$L_1 + L_2 = L$$

$$\sqrt{\epsilon_w} L_1 + \sqrt{\epsilon_s} L_2 = L_{a,total}$$

where  $\epsilon_w$  is the dielectric constant of water,  $L_{a,1}$  is apparent length of probe section embedded in water, which is the measured distance between reflection points 1 and 2, and  $L_{a,total}$  is the apparent length of the whole sensor probe, which is the measured distance between reflection points 1 and 3.

# Signal Analyses

- Method 1: Determine internal reflections
  - Example result



# Signal analyses

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- Method 2: Bulk dielectric properties
  - Bulk dielectric properties can be relatively easily determined following common procedures

# Bulk Dielectric Constant

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## □ Mixing formulas for dielectric constant

$$\frac{L_1}{L} \sqrt{K_{a,bs}} + \frac{L_2}{L} \sqrt{K_{a,w}} = \sqrt{K_{a,m}} \quad (\text{mixing formula for the overall system})$$

$$(1-n) \sqrt{K_{a,s}} + n \sqrt{K_{a,w}} = \sqrt{K_{a,bs}} \quad (\text{mixing formula for saturated soil deposit})$$

$$\Rightarrow \frac{\sqrt{K_{a,m}}}{\sqrt{K_{a,w}}} = 1 - \frac{(1-n) \left( 1 - \frac{\sqrt{K_{a,s}}}{\sqrt{K_{a,w}}} \right)}{L} L_1$$

- Approximate linear relationship between  $K_{a,m}$  and deposition thickness
- Deposition thickness can be estimated

# Bulk Electrical Conductivity

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## □ Mixing for electrical conductivity

$$EC_{b,bs} \frac{L_1}{L} + EC_w \frac{L_2}{L} = EC_{b,m}$$

Akie's Law : Formation Factor  $F = \frac{EC_{b,bs}}{EC_w} = n^f$

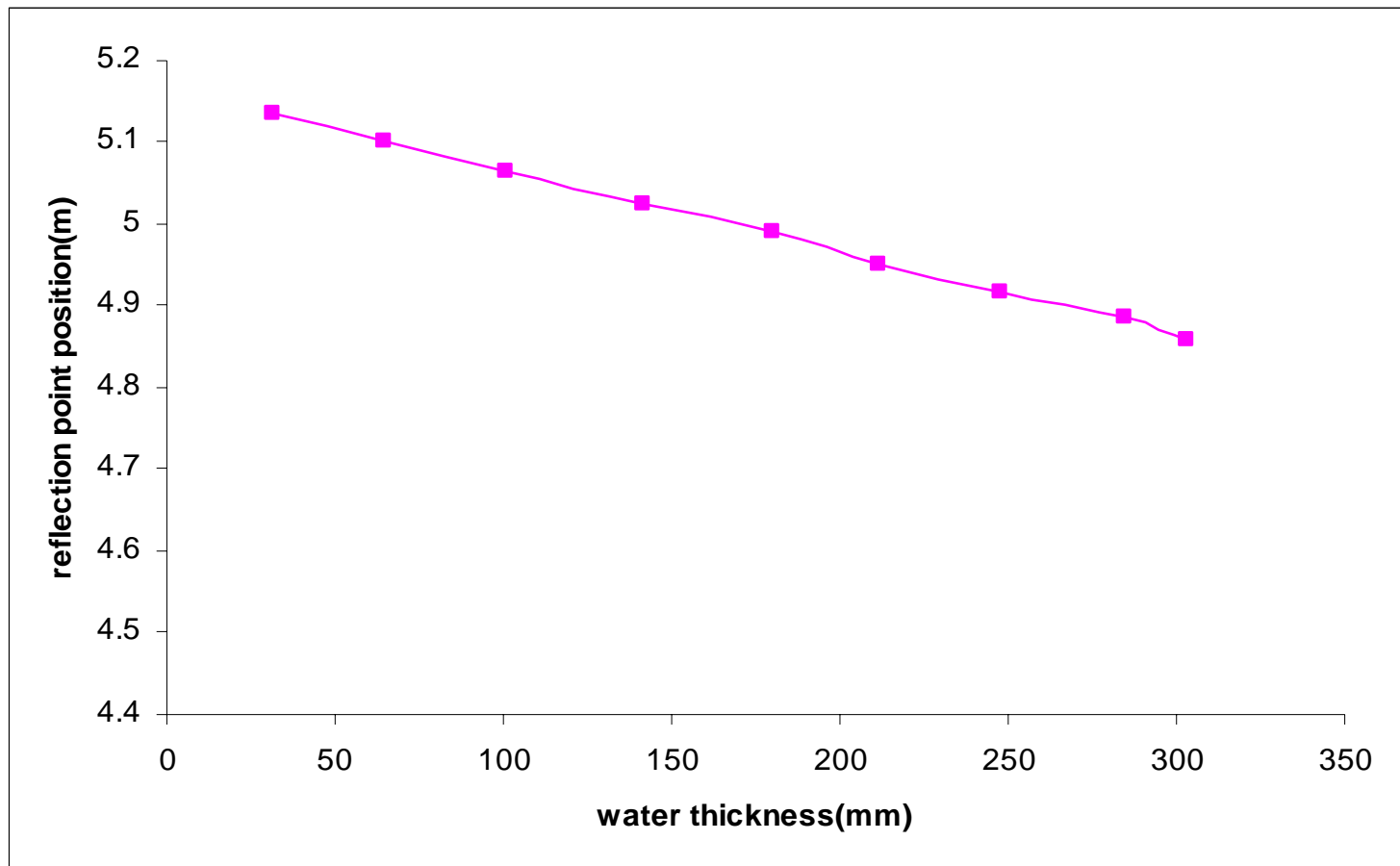
$$\Rightarrow \frac{EC_{b,m}}{EC_w} = 1 - \left(1 - n^f\right) \frac{L_1}{L}$$

- Approximate linear relationship between  $EC_{b,m}$  and deposition thickness at a given electrical conductivity of water

# Results and Analysis

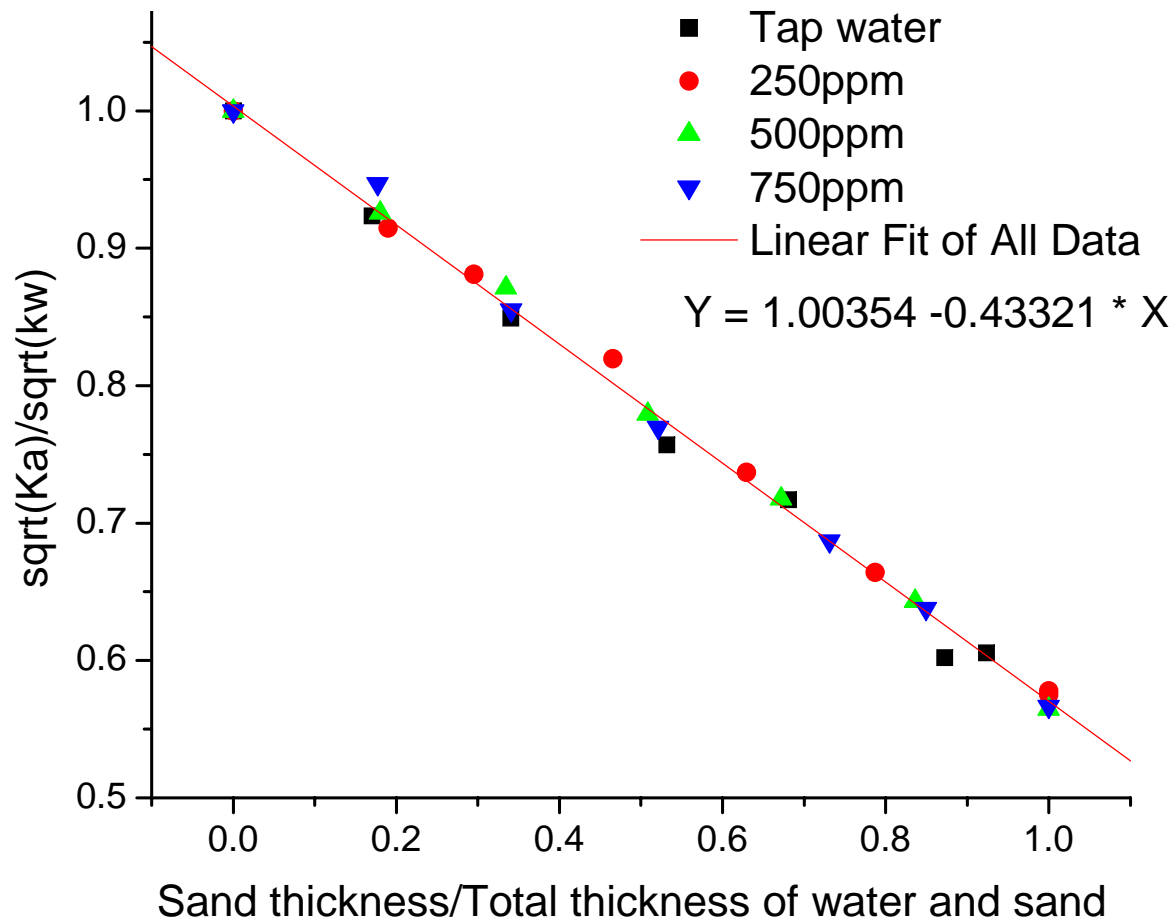
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- Estimate water level from location of surface reflection



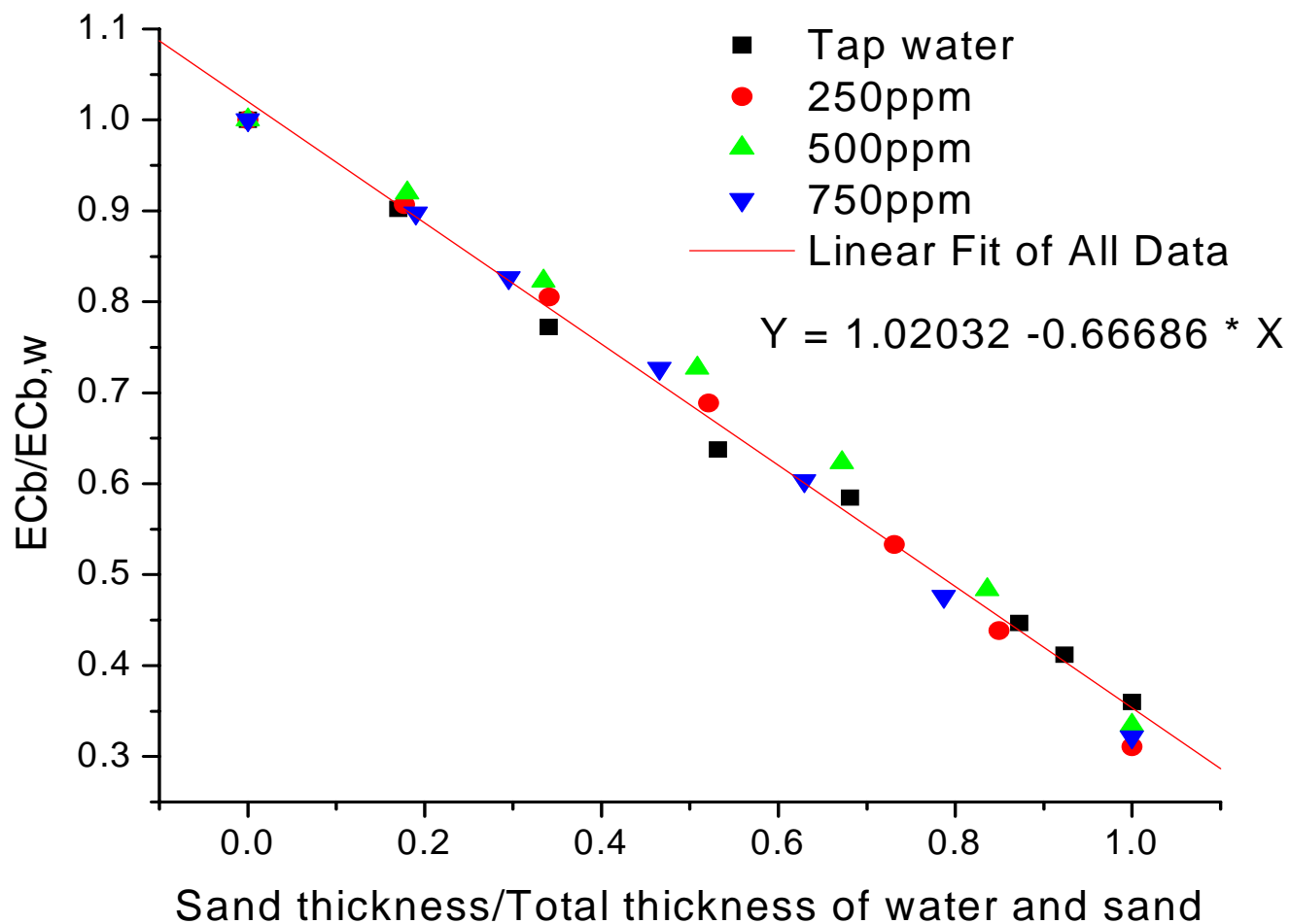
## Results and Analysis

- Example of TDR measured dielectric constant versus deposition thickness (water level kept constant)



## Results and Analysis

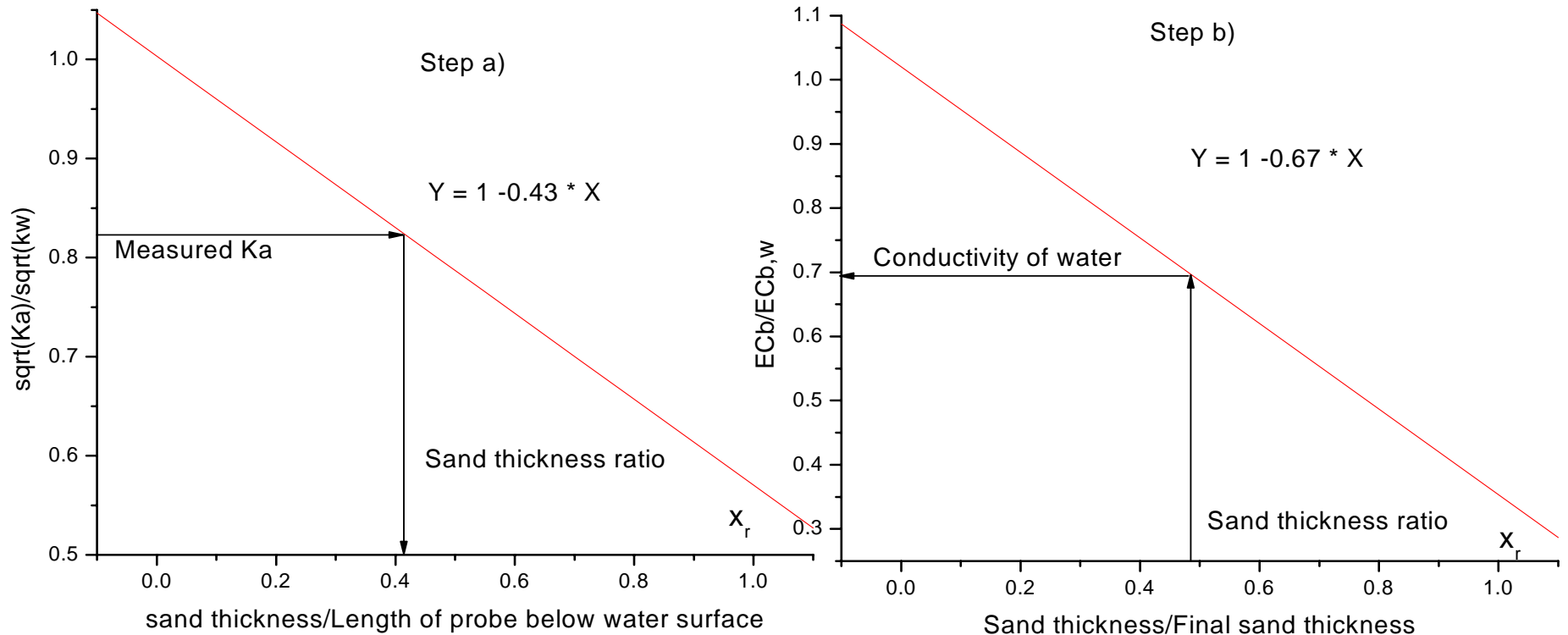
- Example of TDR measured electrical conductivity versus deposition thickness



# Results and Analyses

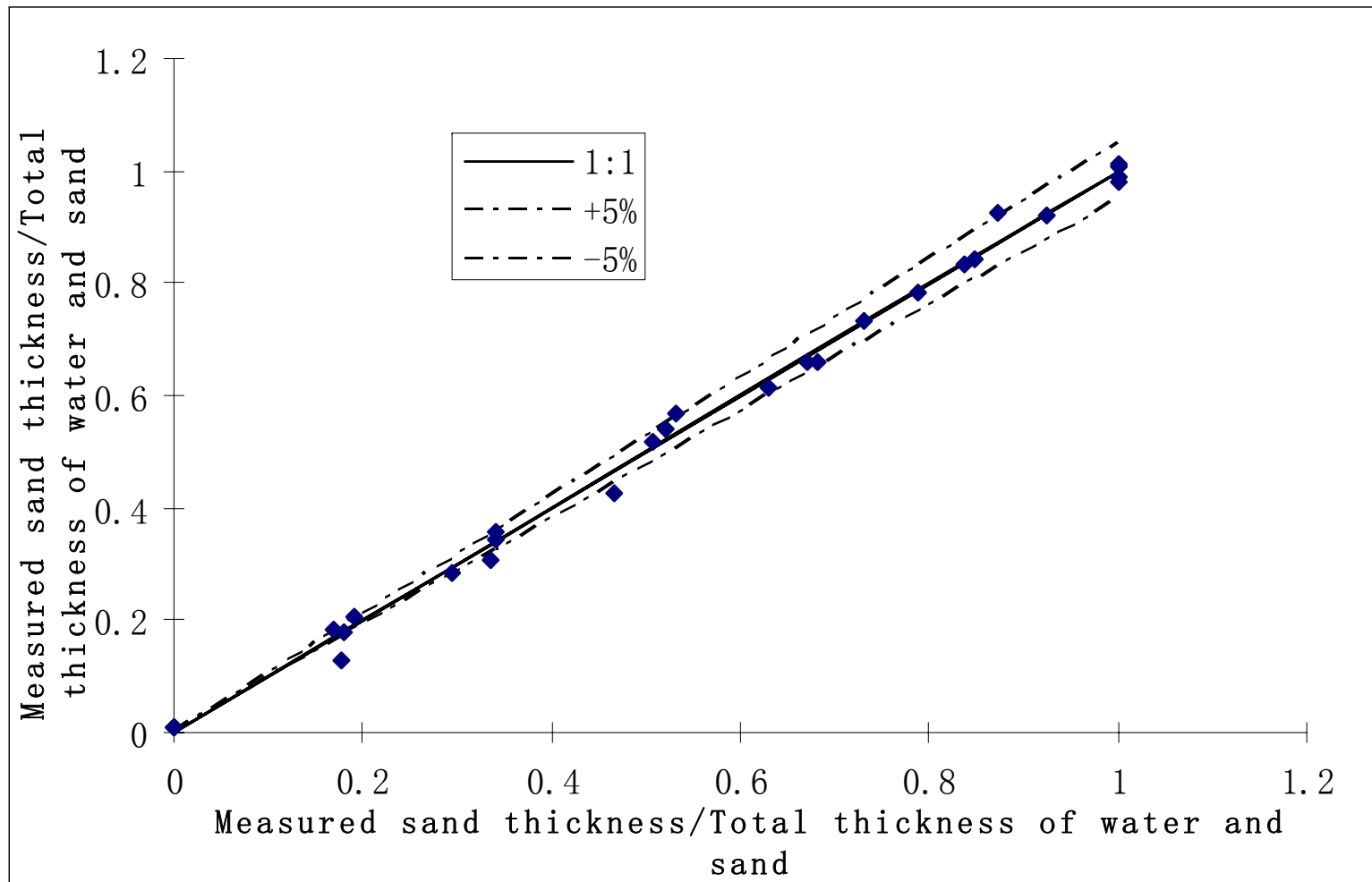
## Application procedures using design equations

- 1) Estimate scour depth; 2) estimate electrical conductivity of water; 3) estimate density of sediment



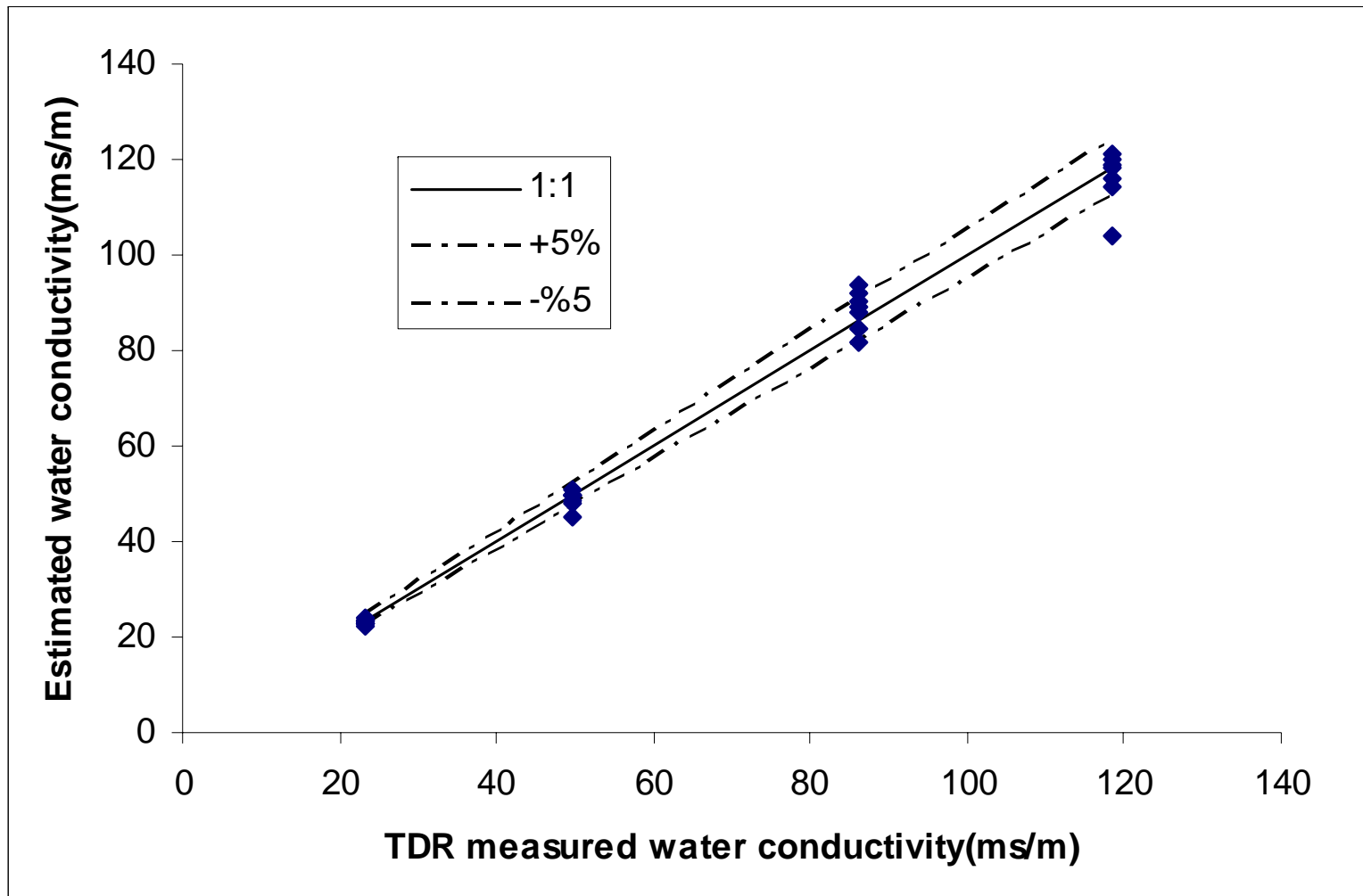
# Results and Analysis

## Estimated sediment thickness



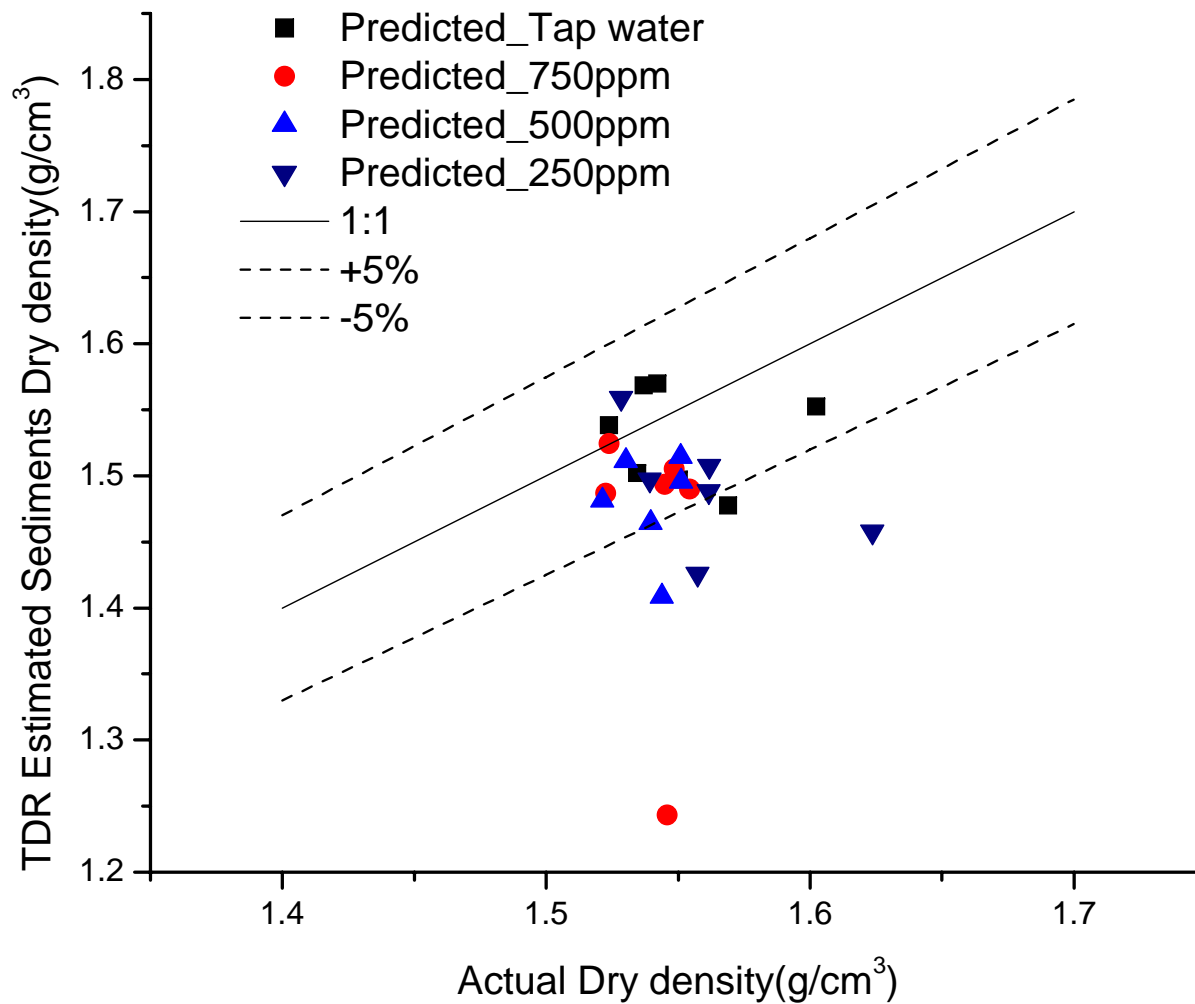
# Results and Analysis

## Estimated electrical conductivity of water



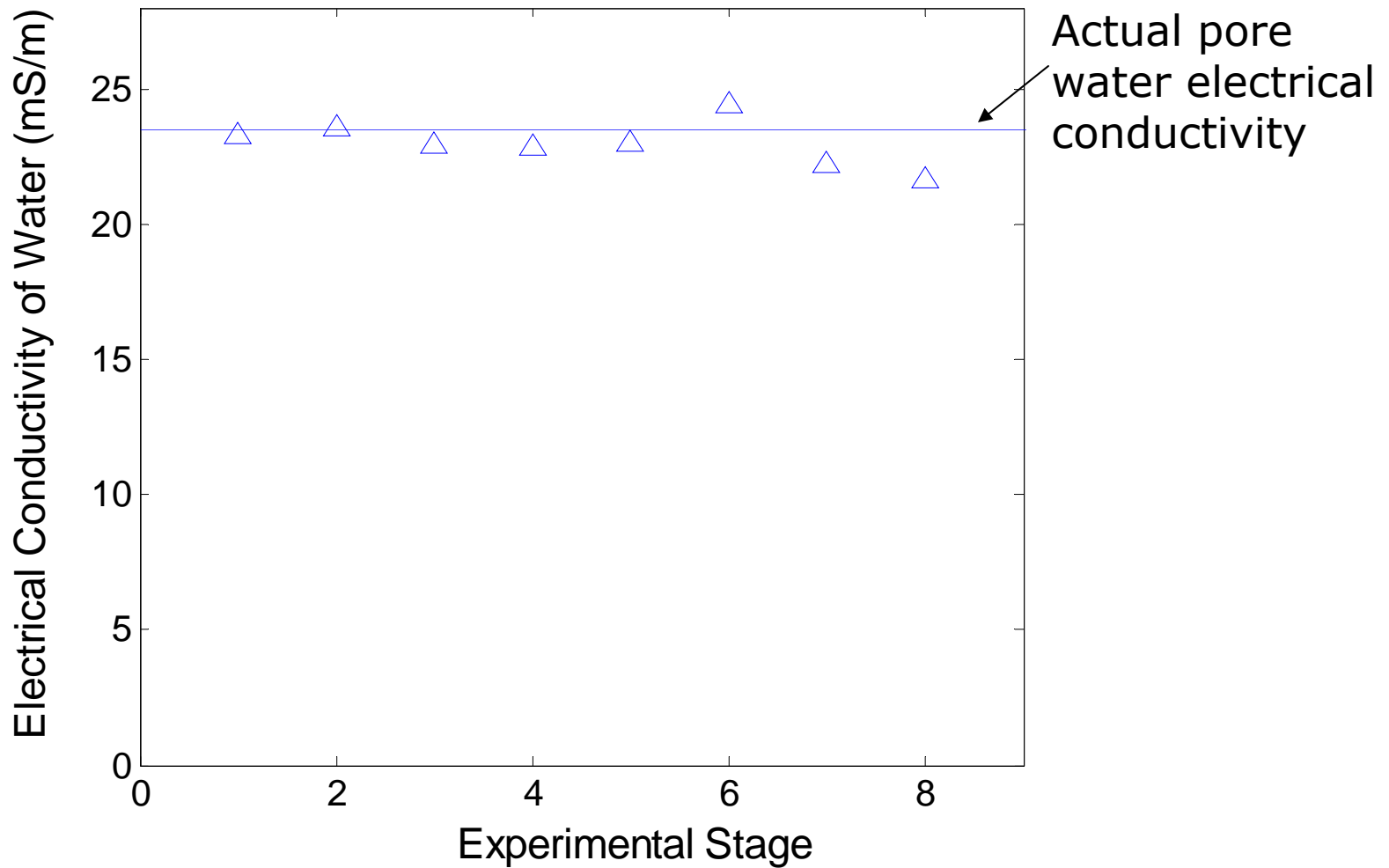
# Results and Analysis

## Estimated density of sediments

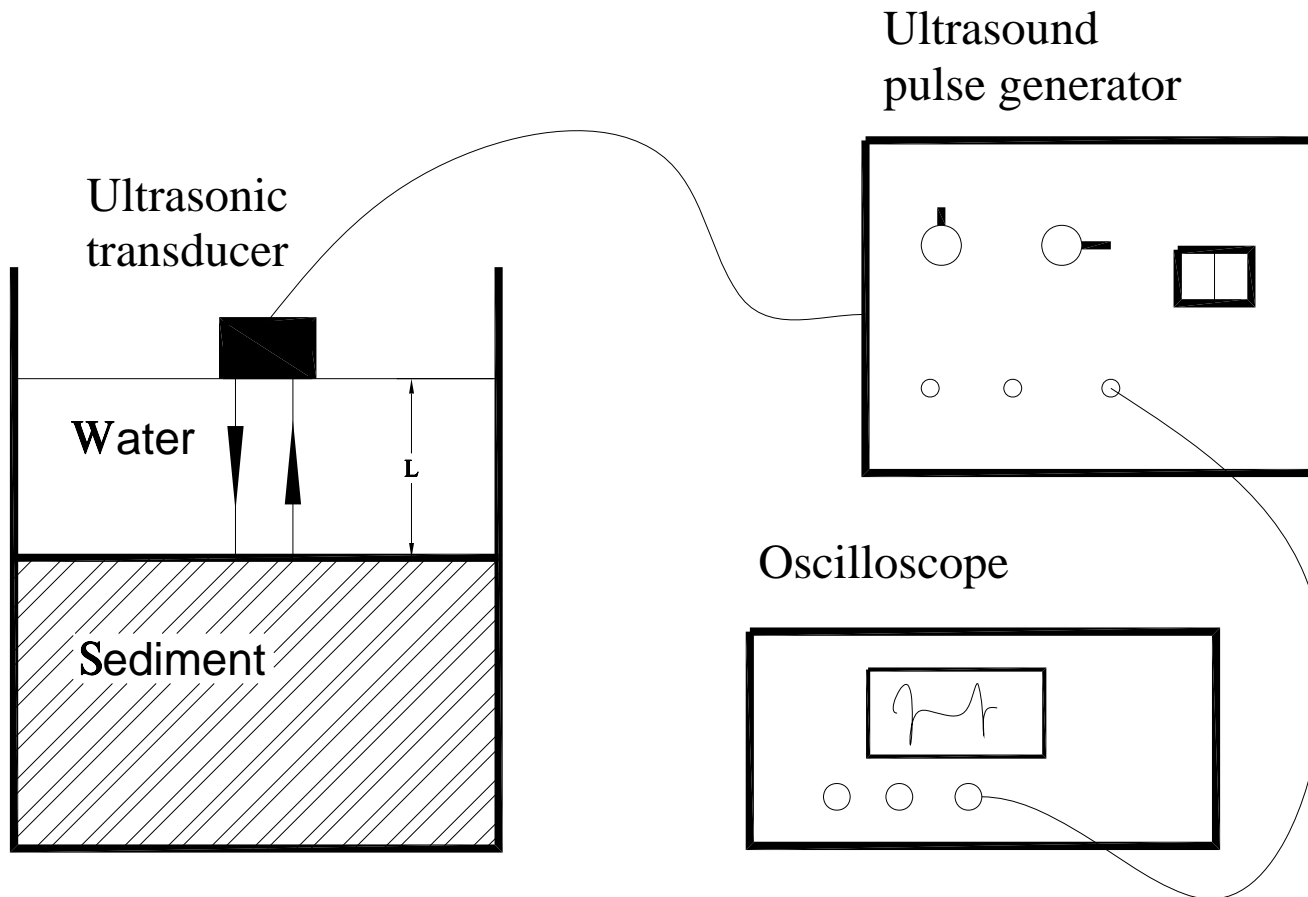


# Results and Analysis

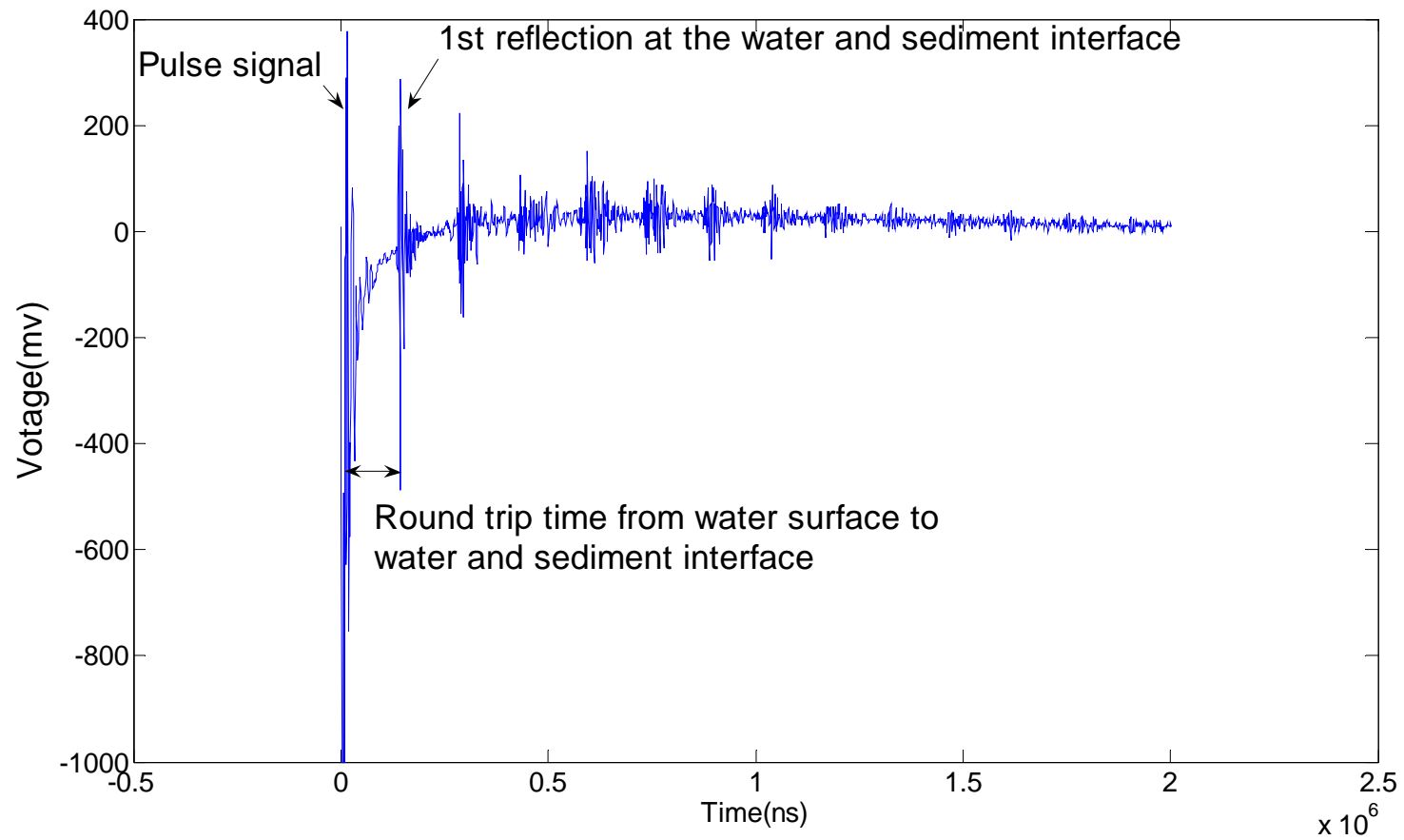
## □ Estimation of Pore Water Electrical Conductivity



# Ultrasonic system



# Example ultrasonic signal

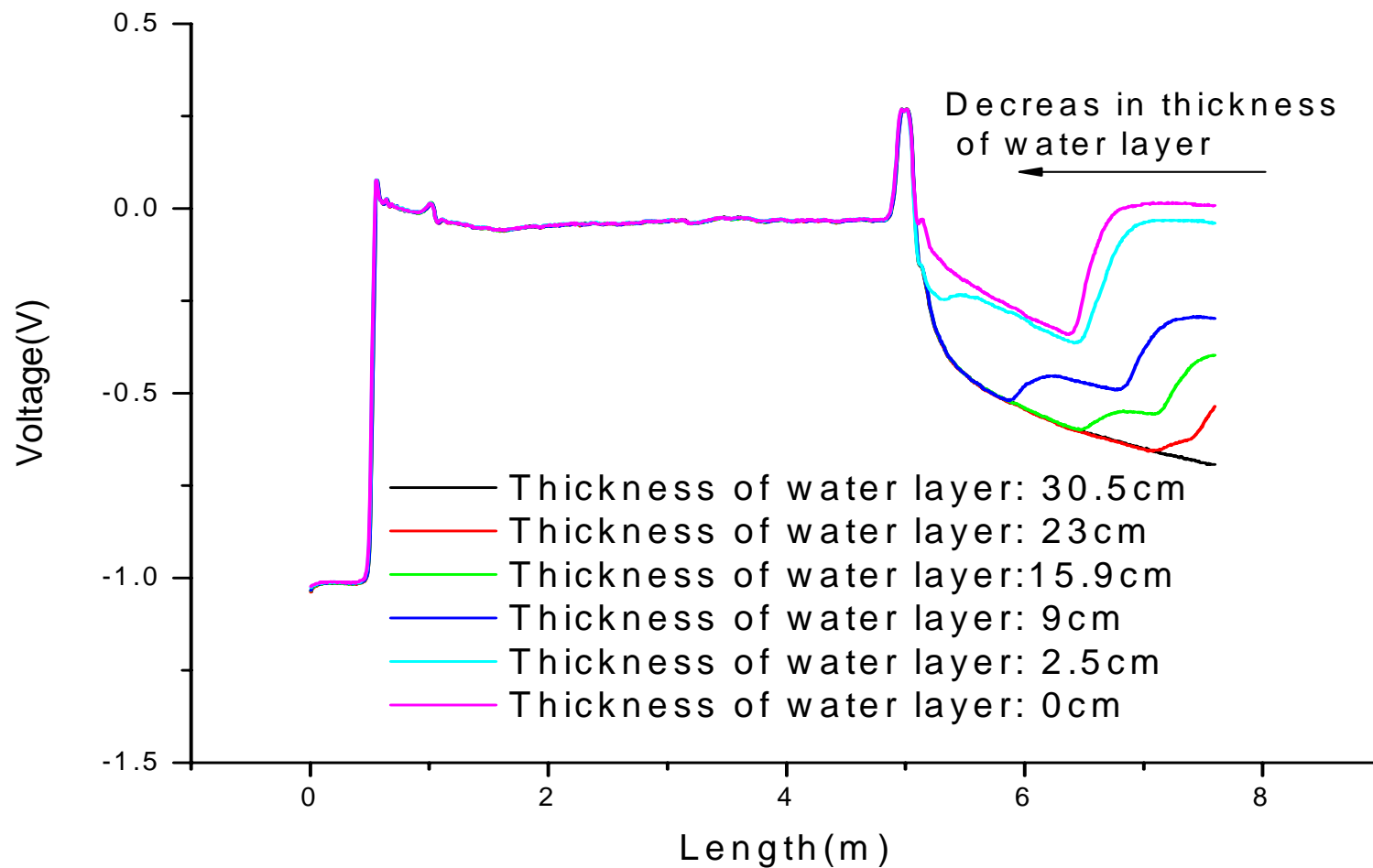


# Set up for Comparing TDR and Ultrasonic Method

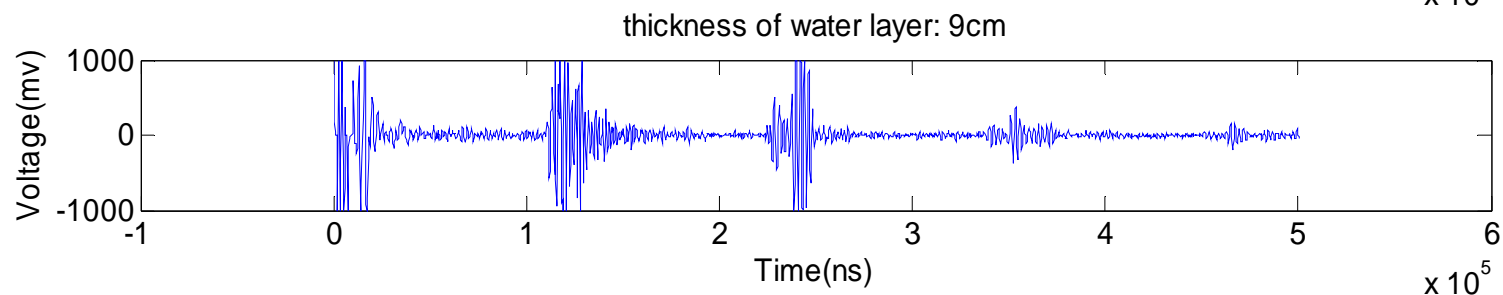
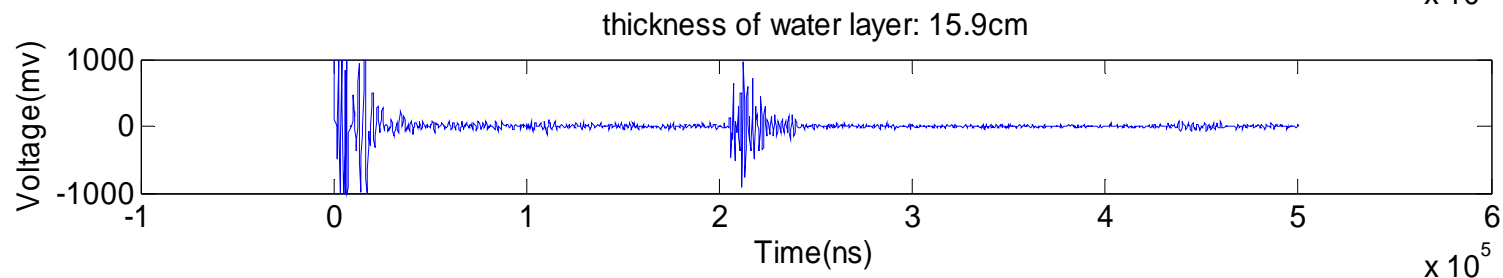
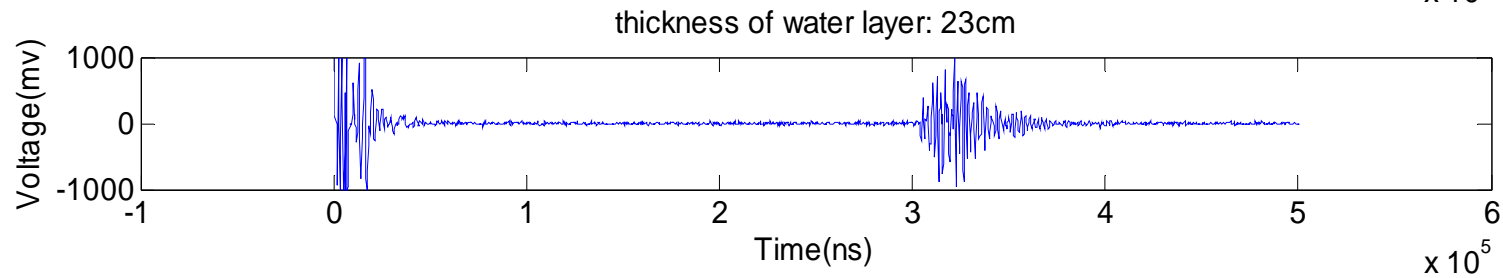
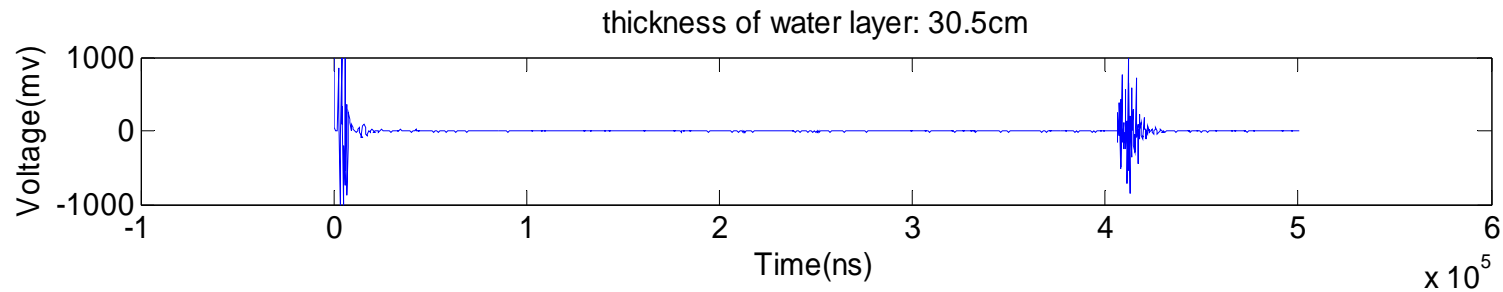
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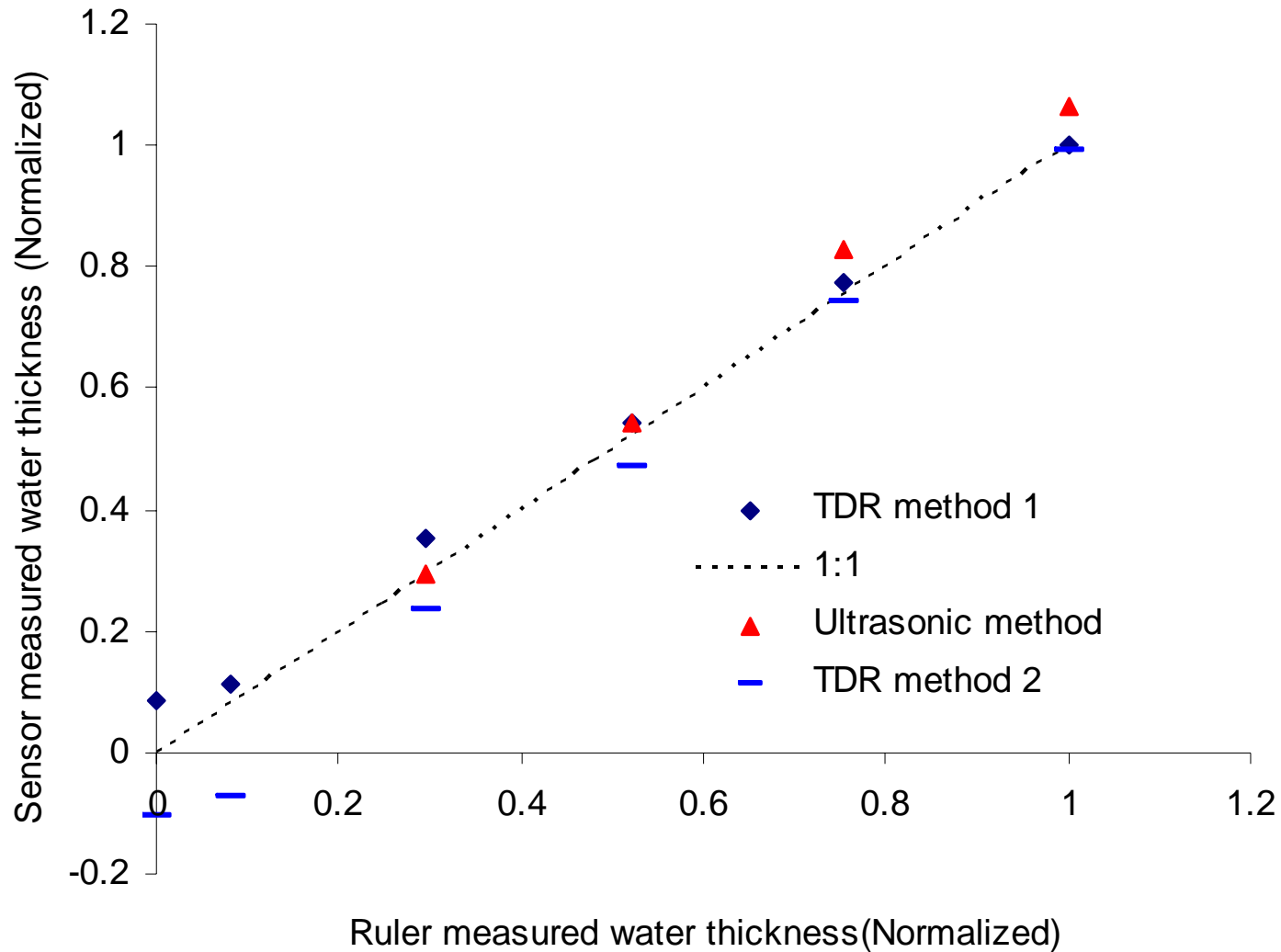
# Example of TDR signal



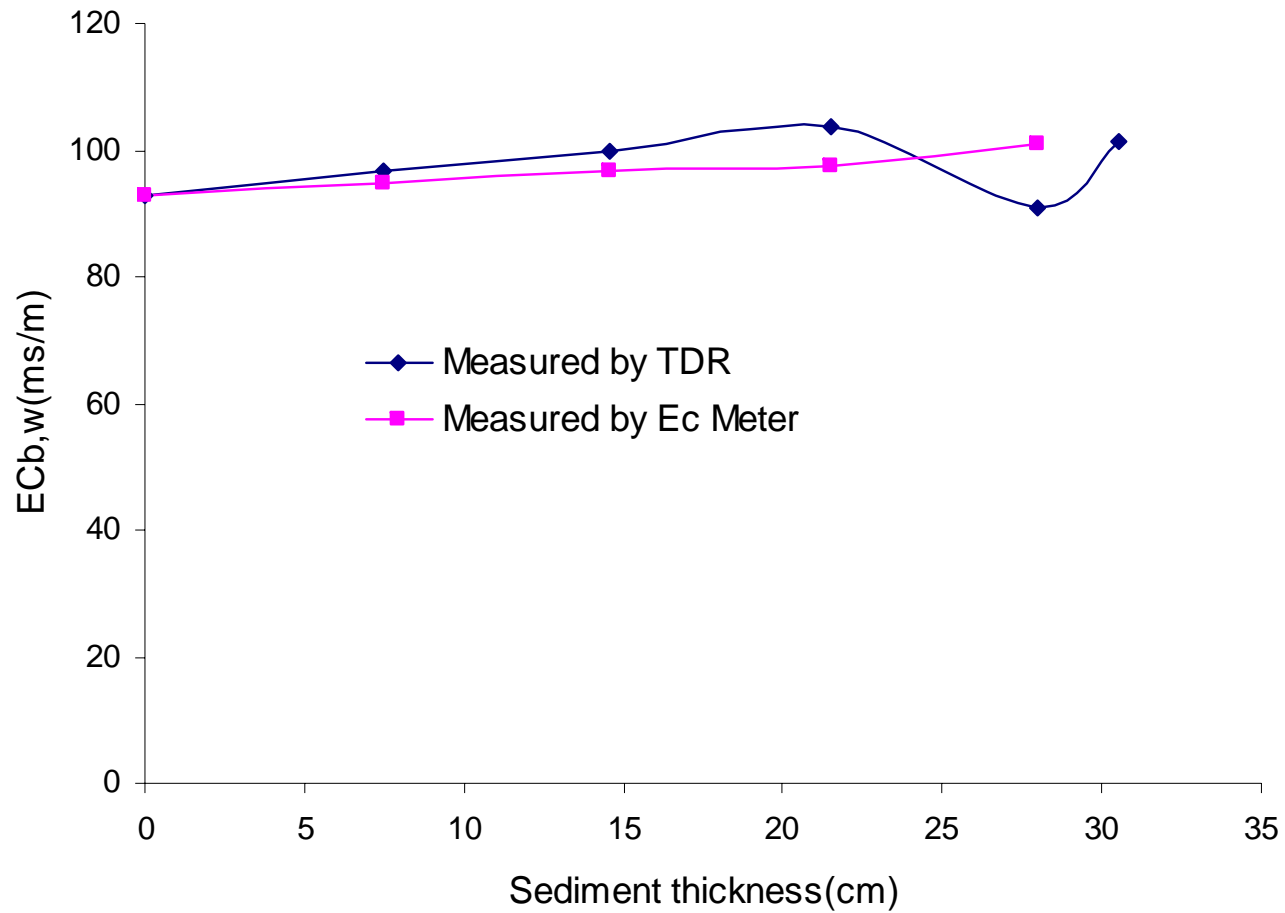
# Example of Ultrasonic Signal



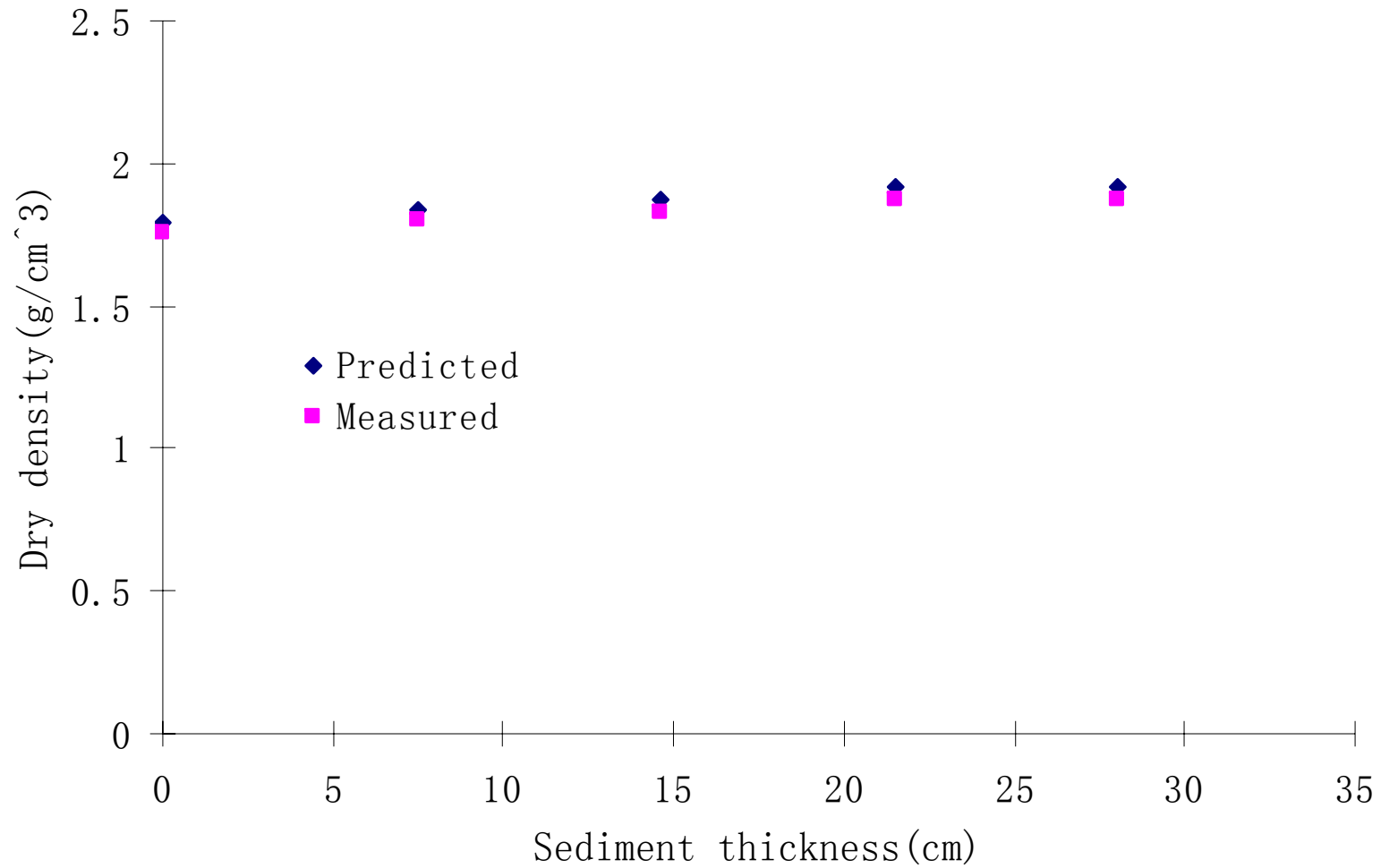
# Comparison of TDR and Ultrasonic Results



## □ TDR electrical conductivity



## □ TDR estimated sediment dry density



# Comparison of TDR and Ultrasonic Method

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- ❑ Both TDR and ultrasonic methods accurately measure scour depth.
- ❑ TDR system:
  - Inexpensive and automatic => real time scour monitoring and surveillance system.
  - Information on sediment status (density) and water conditions (electrical conductivity) are obtained simultaneously. These could be used to enable a mechanistic understanding of scour phenomena.
  - Accuracy of TDR can be affected by the electromagnetic interference and signal attenuation in the cable length.
  - TDR sensor only measures scour at a given point. Multiple TDR probes will be needed to map the scour hole shape. This requires the designed field TDR probes to be rugged and inexpensive. The deployment of the TDR probes also needs to be well planned.
- ❑ Ultrasound method:
  - post-event scour measurement.
  - Coupling the ultrasonic transducer with water is needed which requires the ultrasonic transducer to be maintained below the water level.
  - Ultrasonic method is also a local measurement. However, as it is a non-intrusive technology, ultrasonic transducer can be moved to determine the shape of river bed after scour event.
  - The interpretation of ultrasonic signal can be challenging especially for complex river bed territories. Experience from this research indicated that there could be significant amount of background noise in the ultrasonic signal. Experience in ultrasonic signal analyses is needed to ensure a sound interpretation of measurement results.

## Summary and Recommendations

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- ❑ Instrument of bridge scour/sedimentation is critical for bridge safety
- ❑ A new approach has been developed for TDR
  - Measure a variety of information related to scour (water level, scour/sedimentation depth, sedimentation status (density&water content), electrical conductivity of water)
  - Data acquisition and analyses can be can be automated to provide real time surveillance
- ❑ TDR and Ultrasonic method has similar performance for riverbed determination
- ❑ Combined TDR and Ultrasonic method for within flood and post-flood survey are recommended



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*Thank You!*