Pile Integrity Testing: History, Present Situation and Future Agenda

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Pile integrity: Meeting the requirements with regard to geometry and materials

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Agenda

- History of piling technology
- Flaws in piles
- History of pile integrity testing
- Testing methods overview
- Present situation
- Future outlook

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Piling – the oldest profession?

London, U.K. 4,600 BC

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Pile driving is still being practiced

Delft 1992

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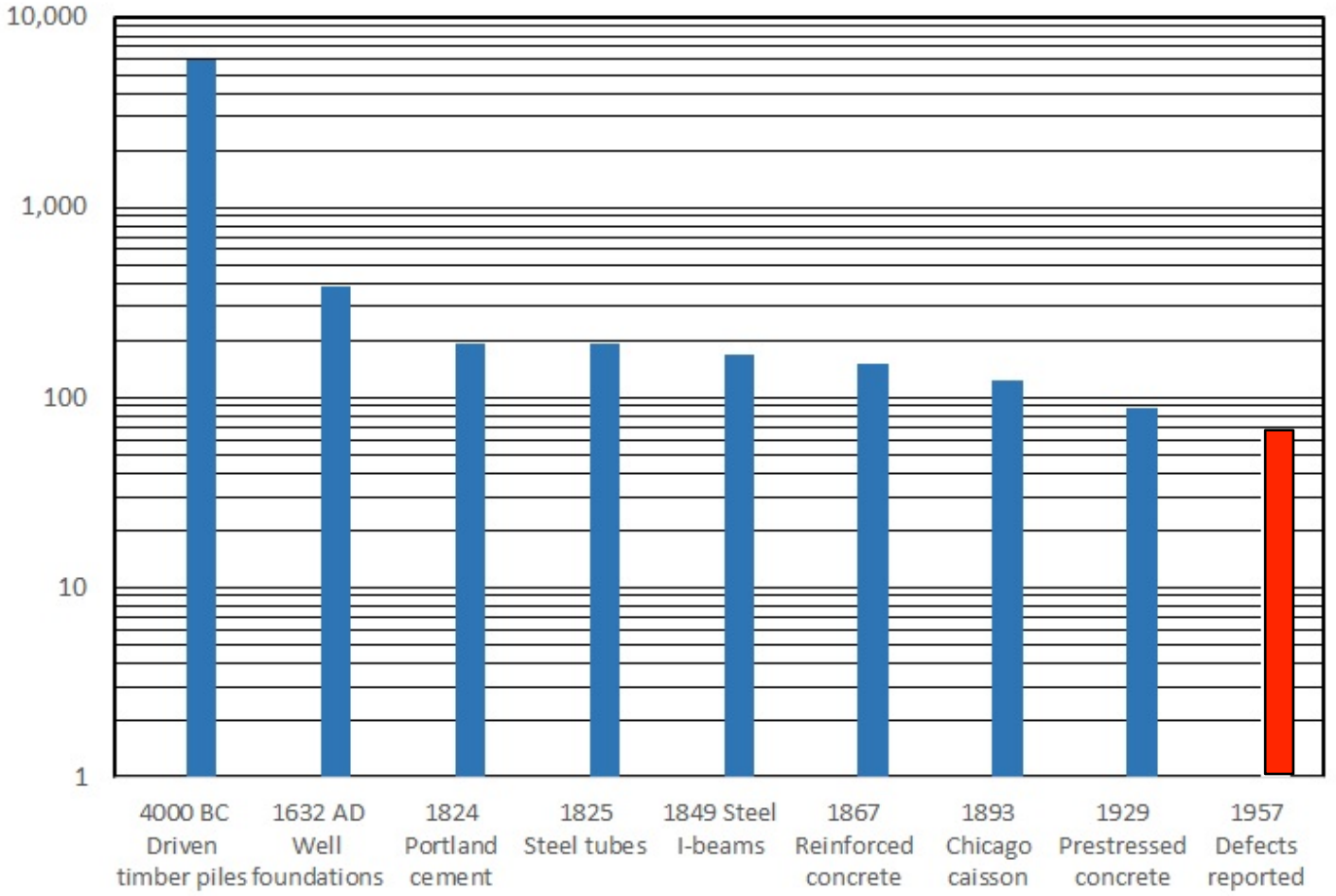
Deep Foundations Technology



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Hobbs
(1957)

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Flaw Occurrence

(Amir & Amir 2008)

Location	No. of piles tested	Testing method	Piles with flaws	
			Number	[%]
United Kingdom	9,550	Sonic (analog)	161	**1.7**
California	2,986	Mostly radioactive	-	**20**
US site X	470	Visual inspection	-	**64?**
US site Y	171	Visual inspection	-	**76?**
Asia	300	Visual inspection	-	**>20**
Italy	6,865	Ultrasonic	811	**12**
Israel site "R"	253	Sonic (digital)	57	**22.5**
	40	Ultrasonic	26	**65**
Israel site "TA"	65	Ultrasonic	28	**43**

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Some pile are eventually exposed…

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While most of them are not…

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Sometimes we can peek inside these piles…

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Or use sound waves instead of light…

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1963

a new discipline was born in France…

PILE INTEGRITY TESTING

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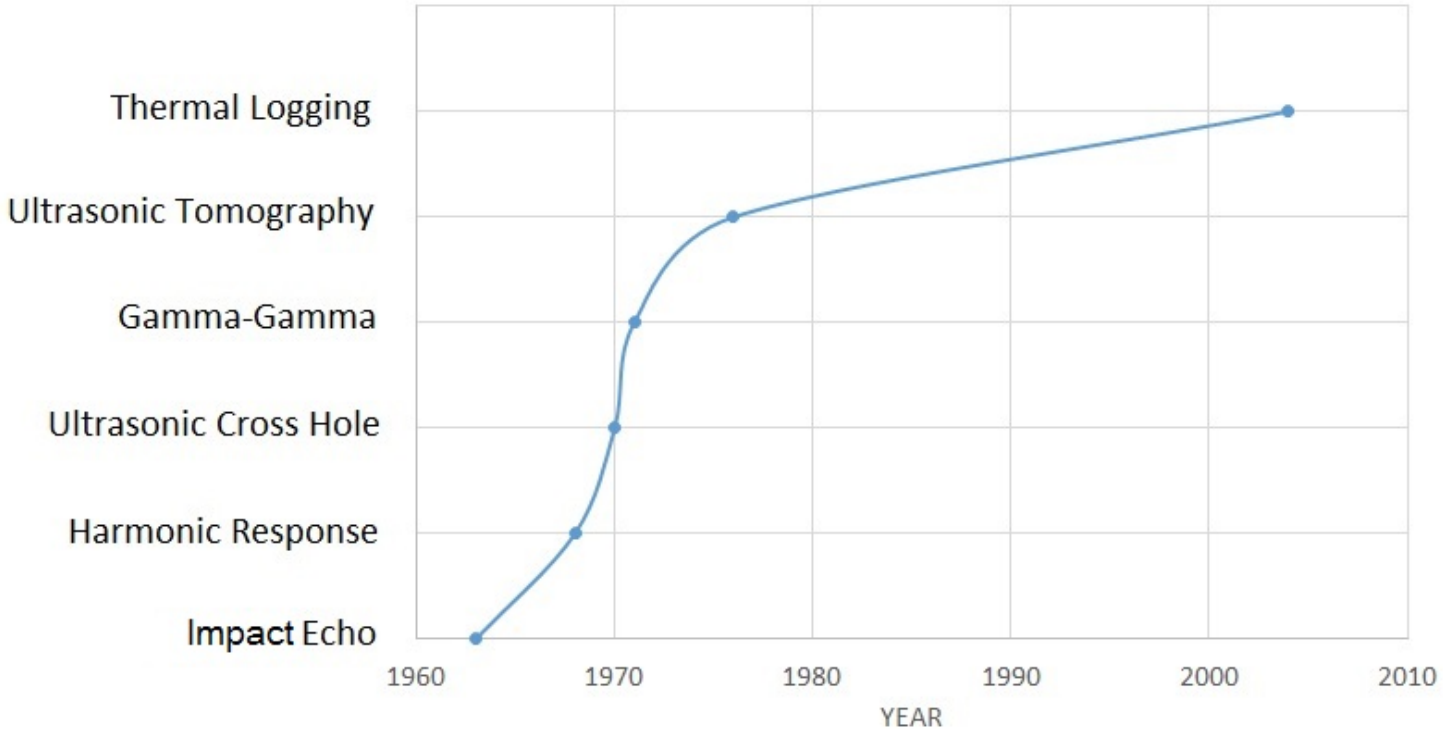
History of pile integrity testing



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Testing methods classification

	Non-intrusive	Intrusive
Acoustic	Impact echo Harmonic response	Ultrasonic cross-hole
	Parallel seismic	
Other		Radioactive Optical Thermal Inclinometer

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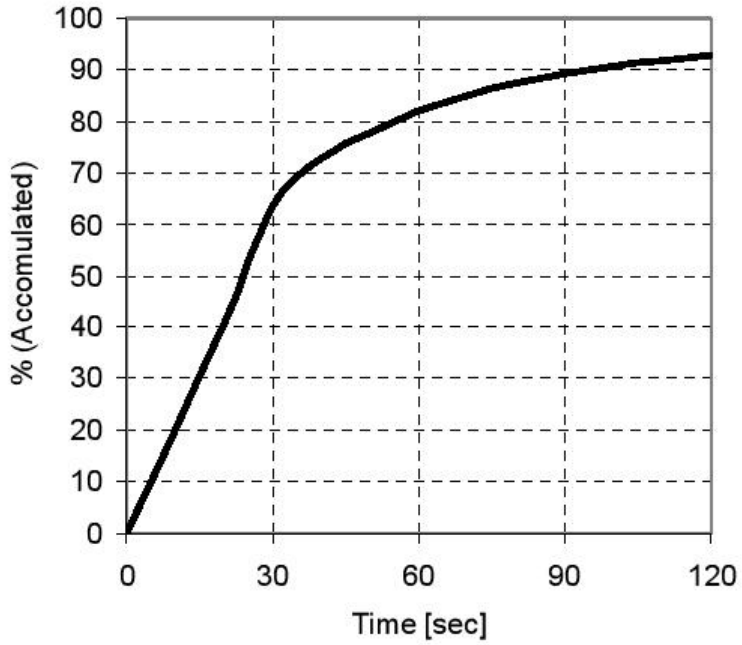
What made Impact-Echo so popular?



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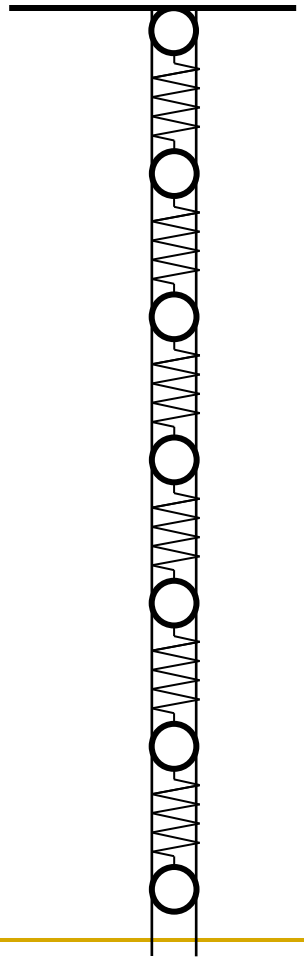
Principle of the method



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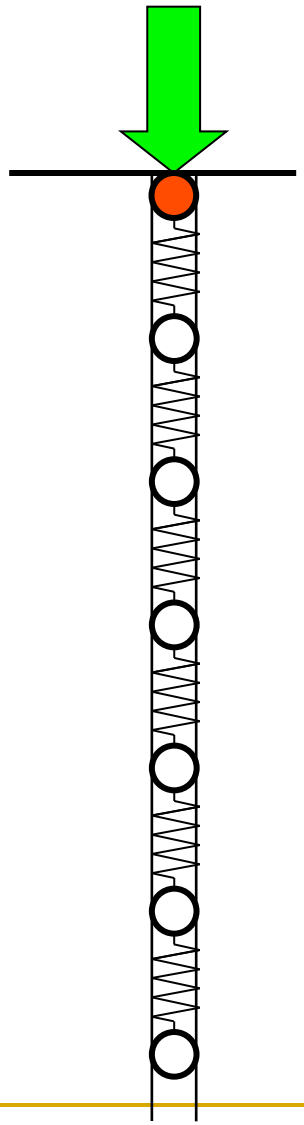

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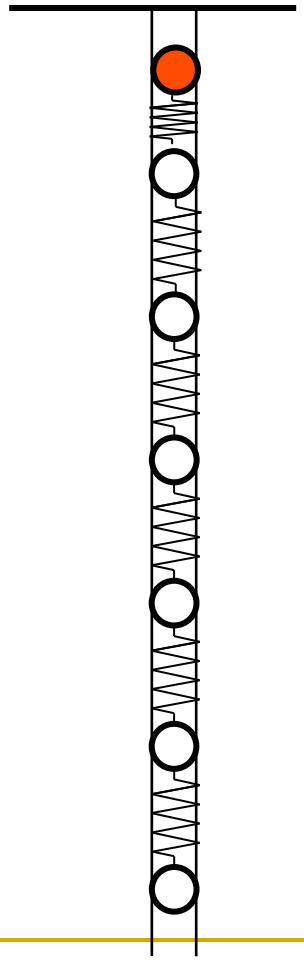

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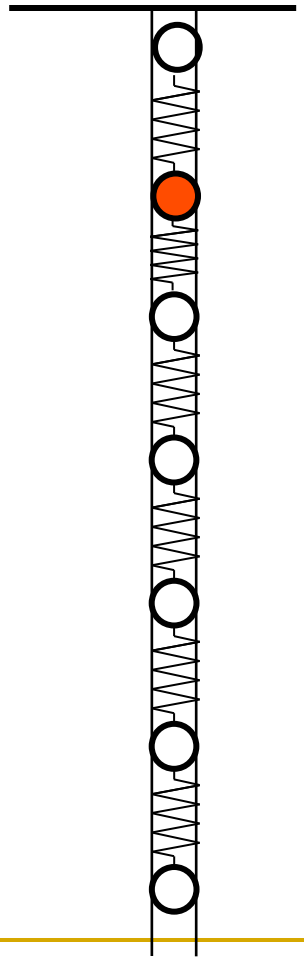

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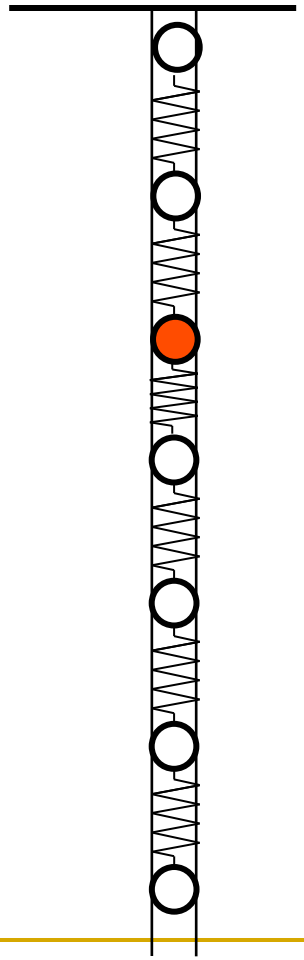

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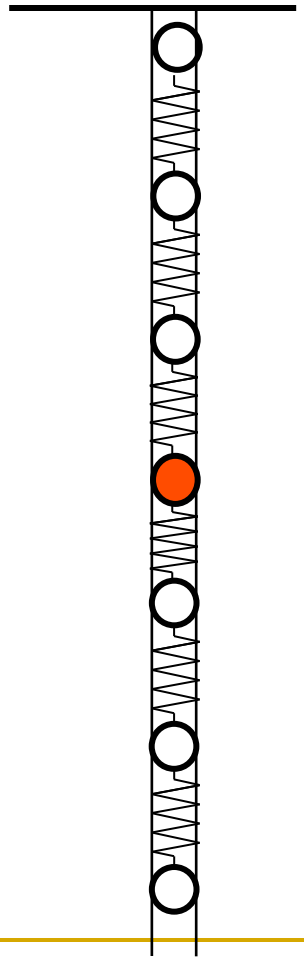

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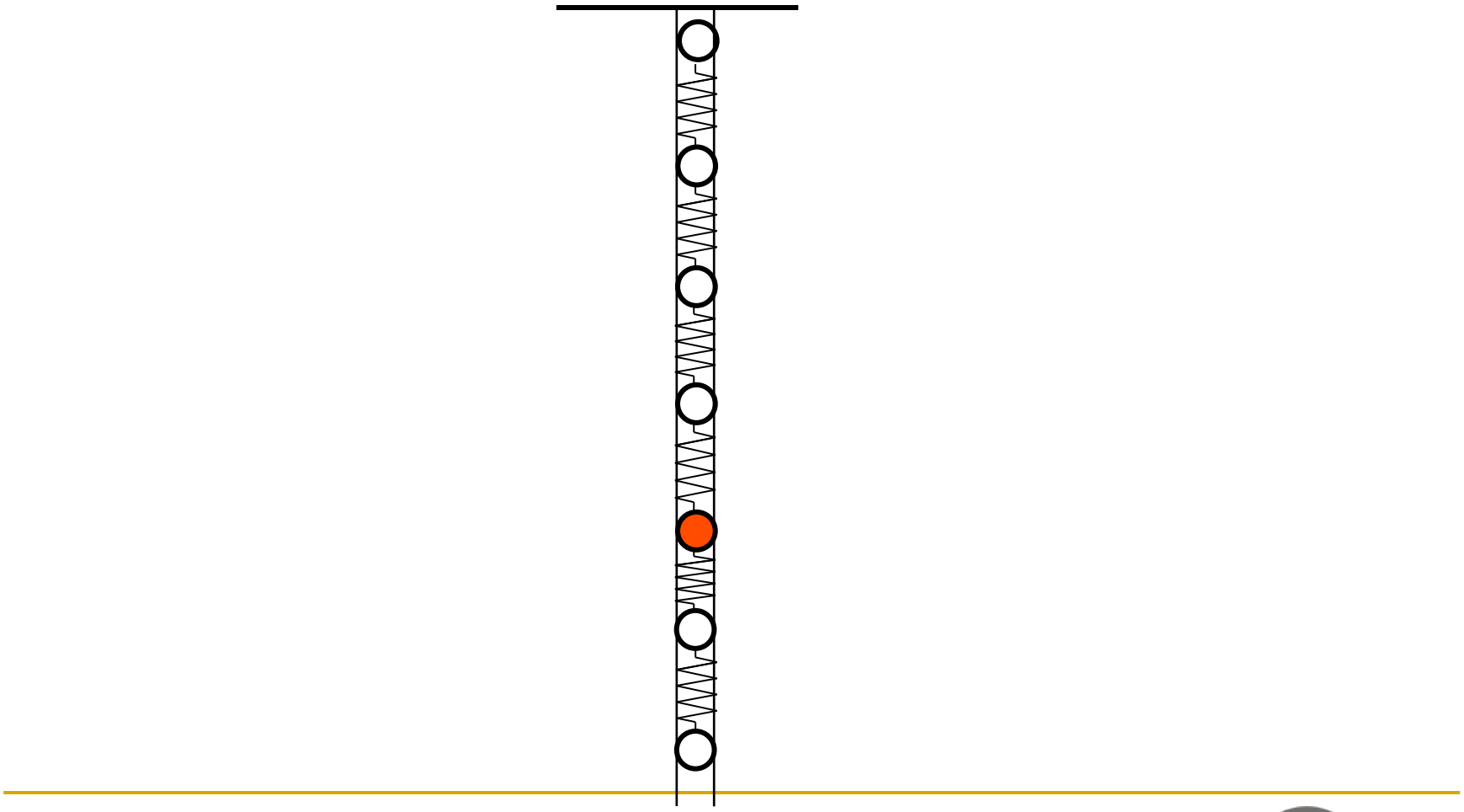

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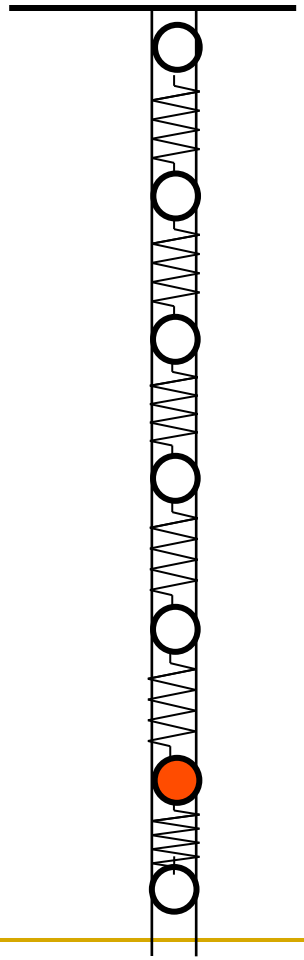

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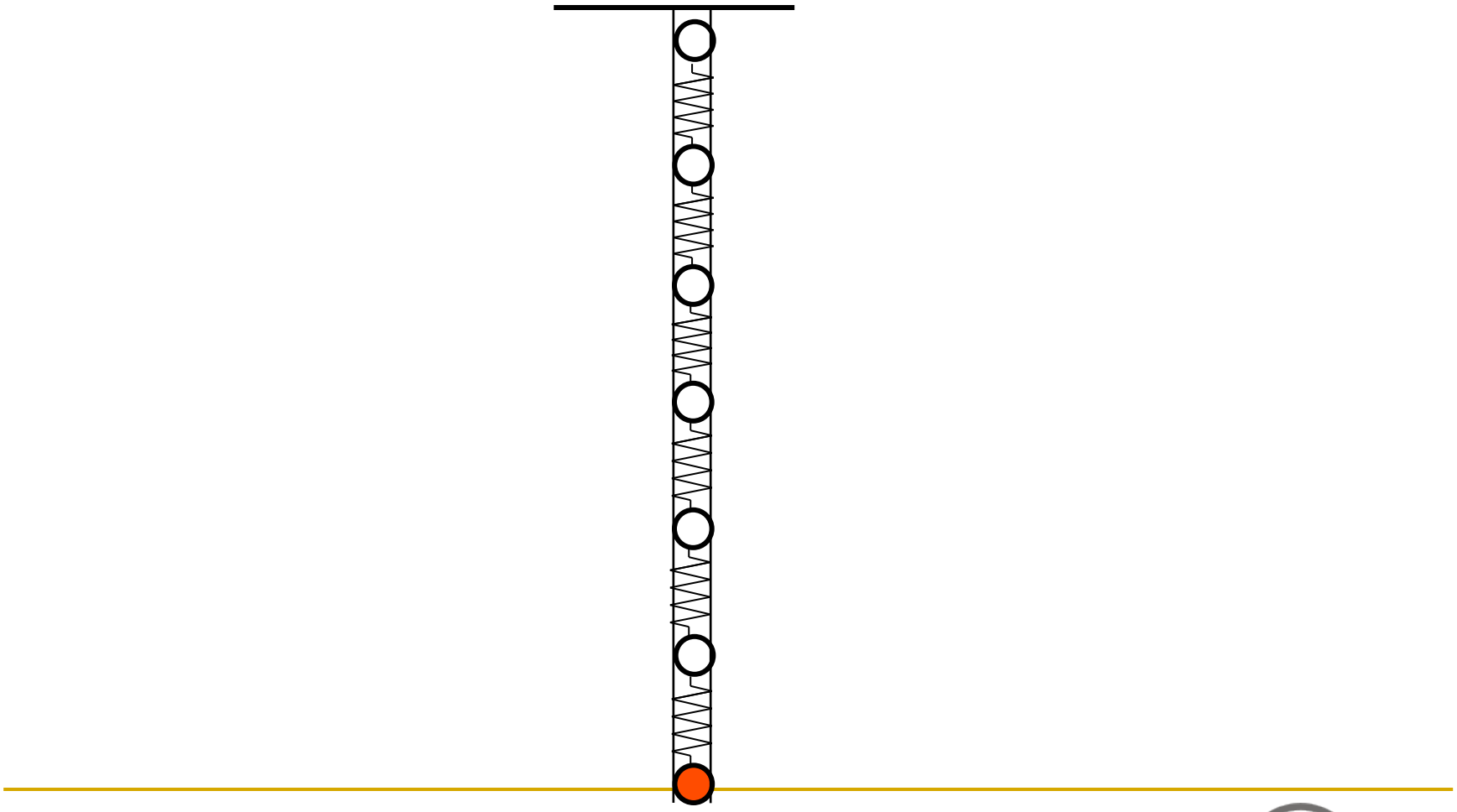

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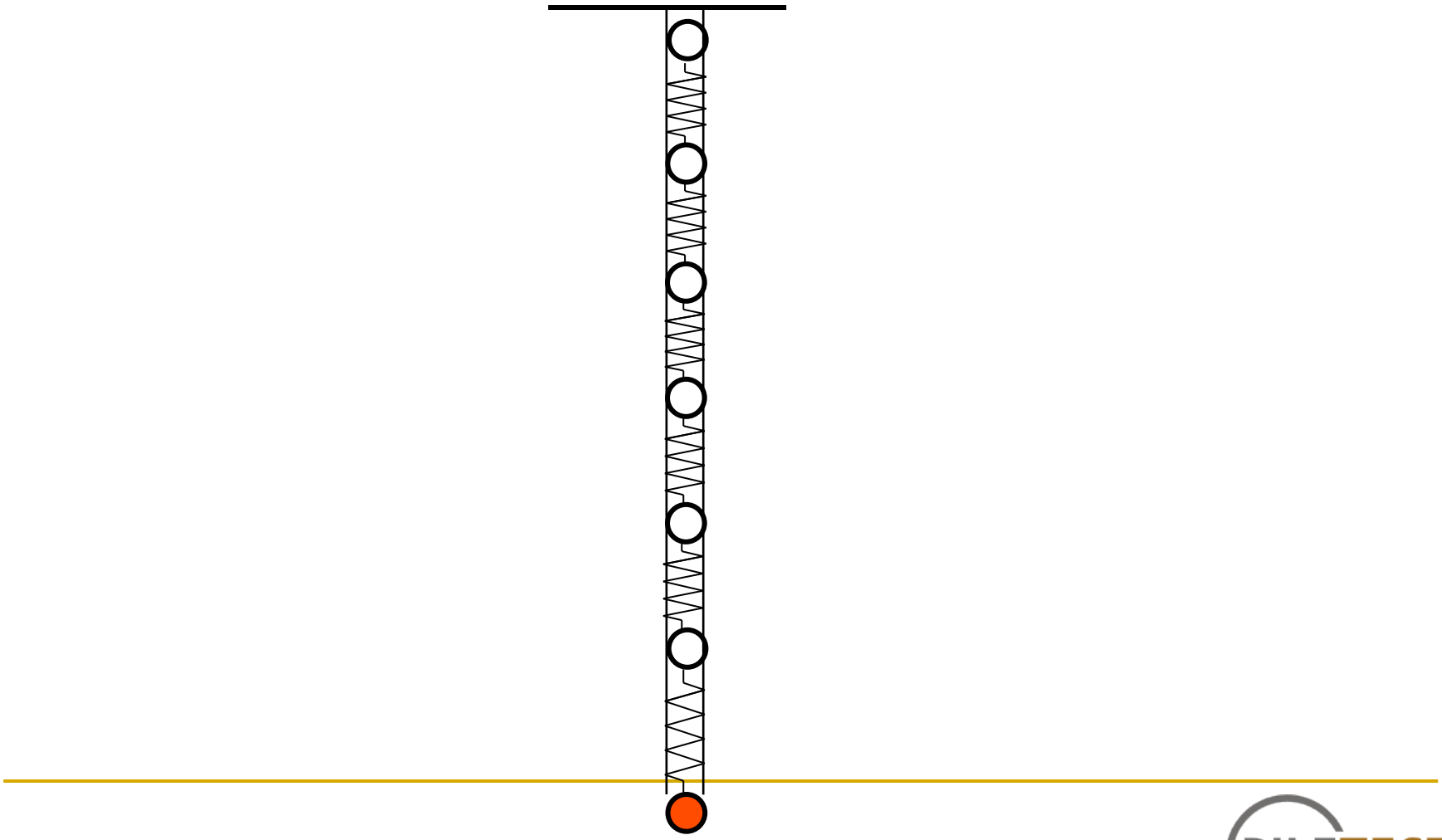

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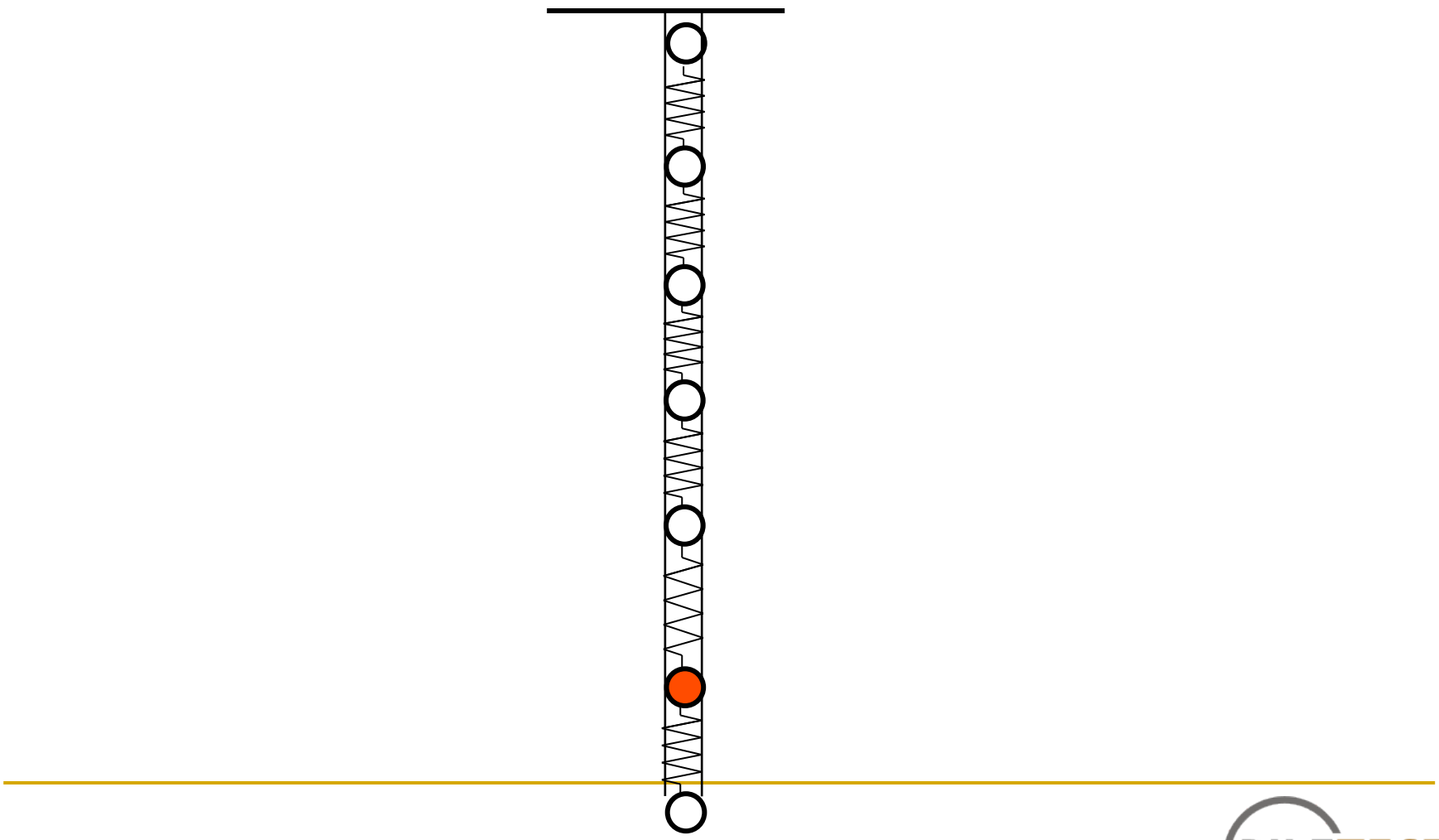

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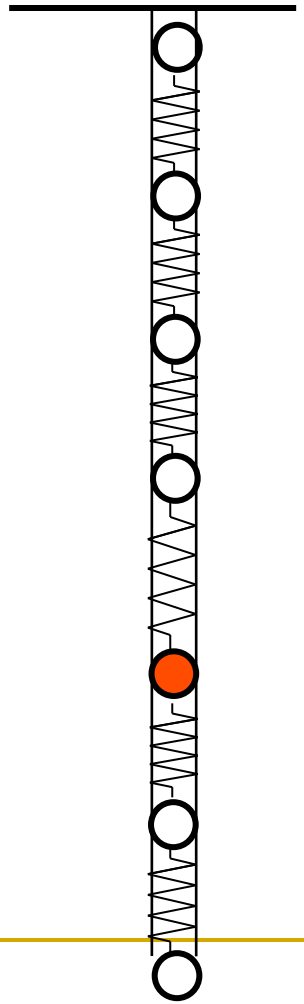

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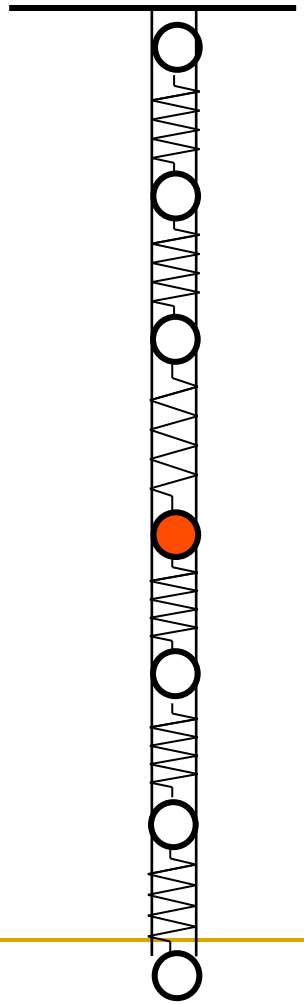

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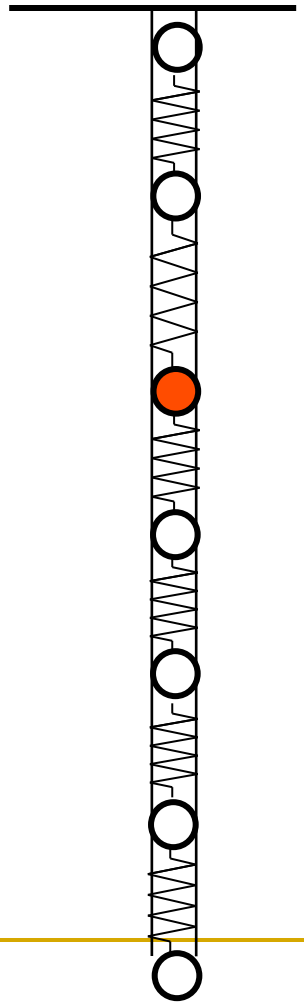

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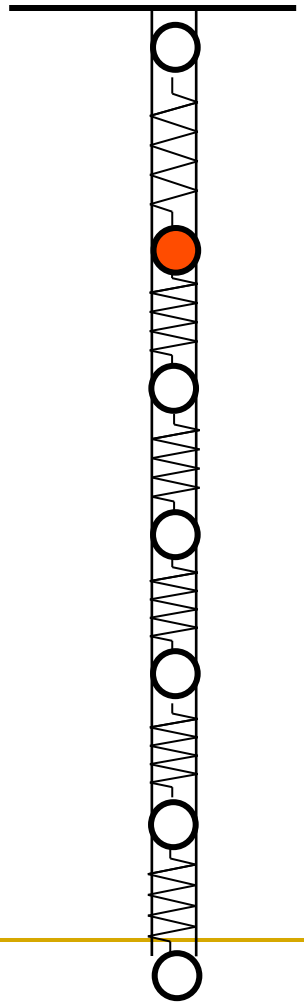

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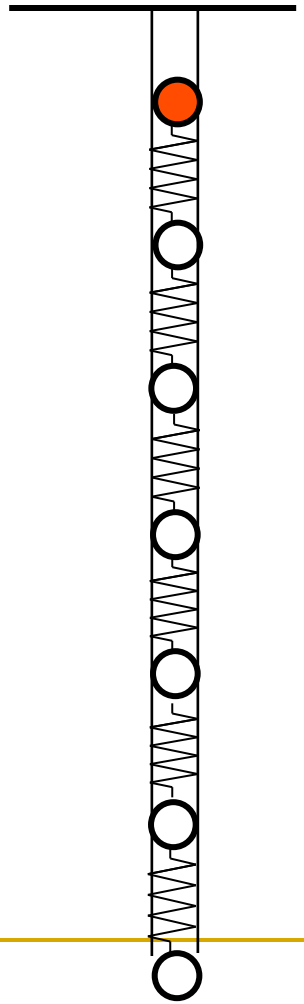

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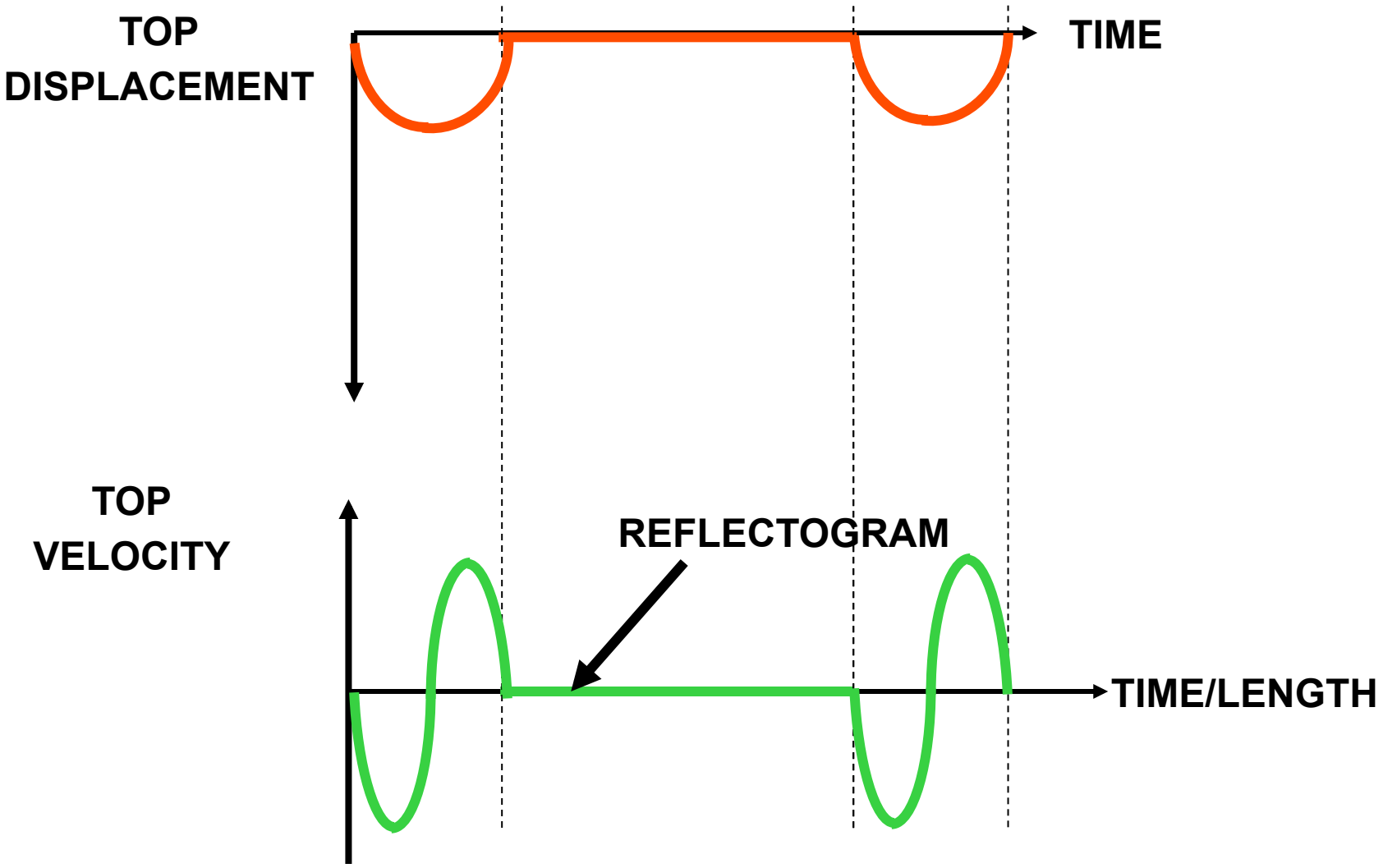

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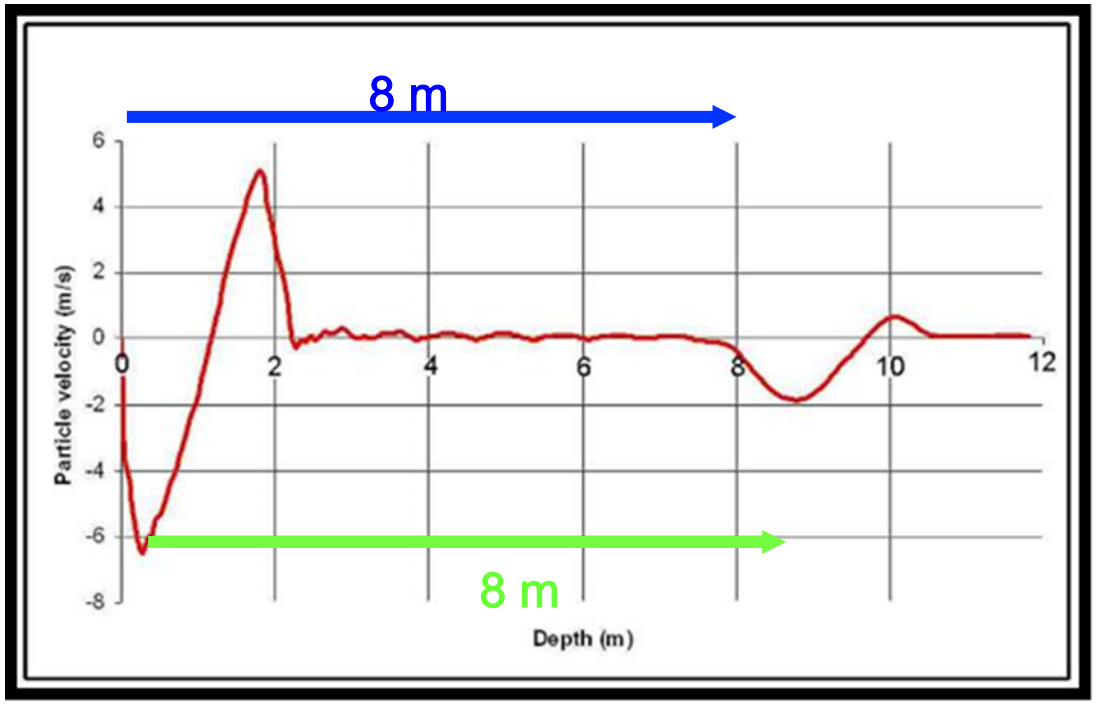
Top particle velocity vs. depth (reflectogram)



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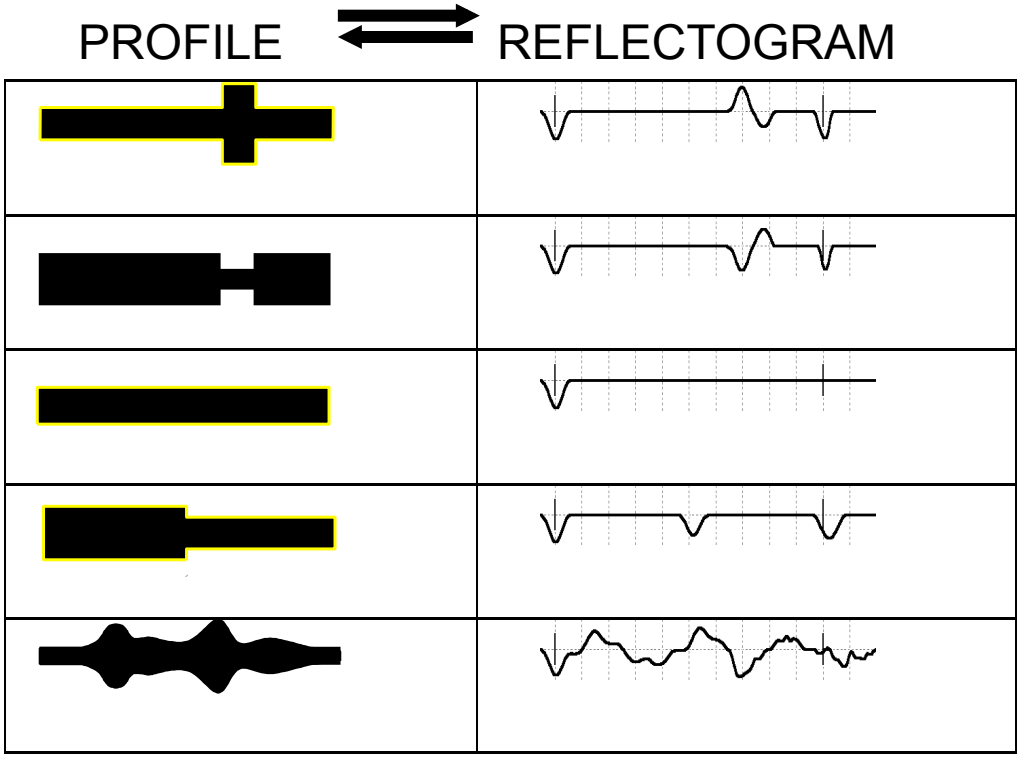
Qualitative interpretation



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1-D wave equation

$$\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2}$$

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c = wave speed

$$c = \sqrt{\frac{E}{\rho}} = K f_c^{1/6}$$

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Skin friction – a blessing for foundation piles

But a problem for integrity testing

$$A = \exp\left(\frac{4L}{D}\frac{\rho_s}{\rho_c}\frac{v_s}{c}\right)$$

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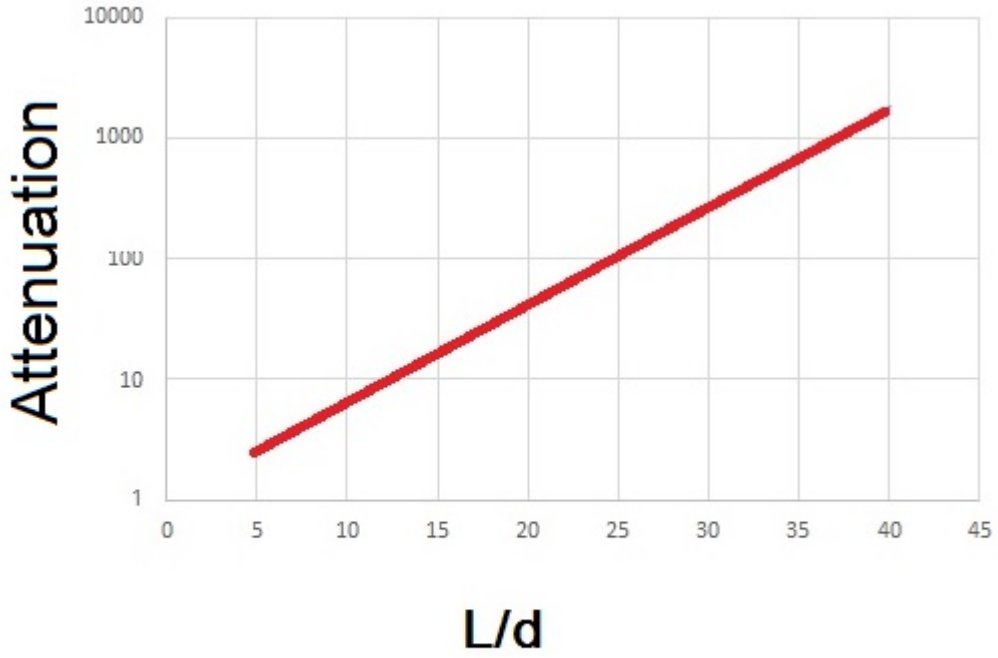
Attenuation vs. L/d (SPT = 20)



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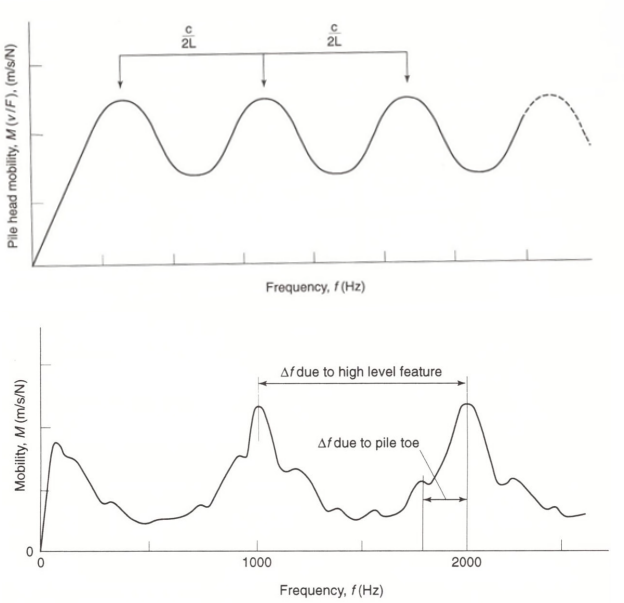
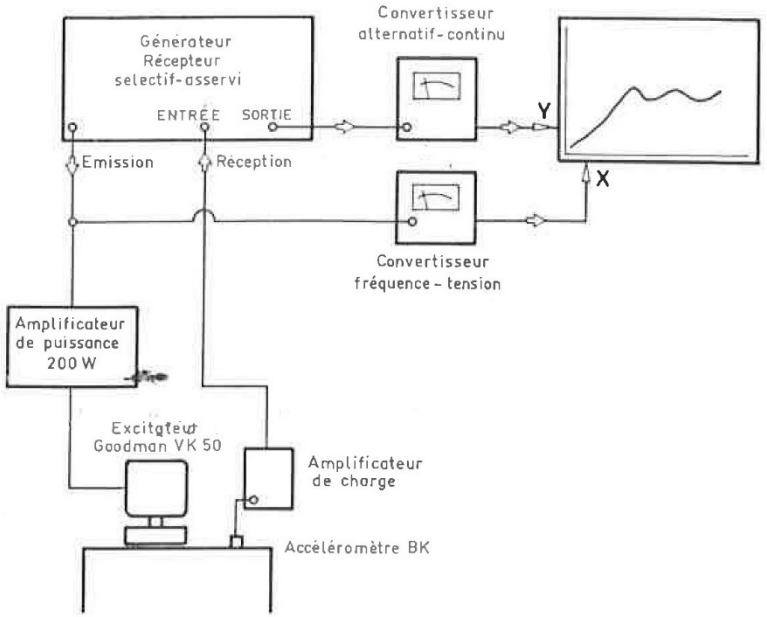
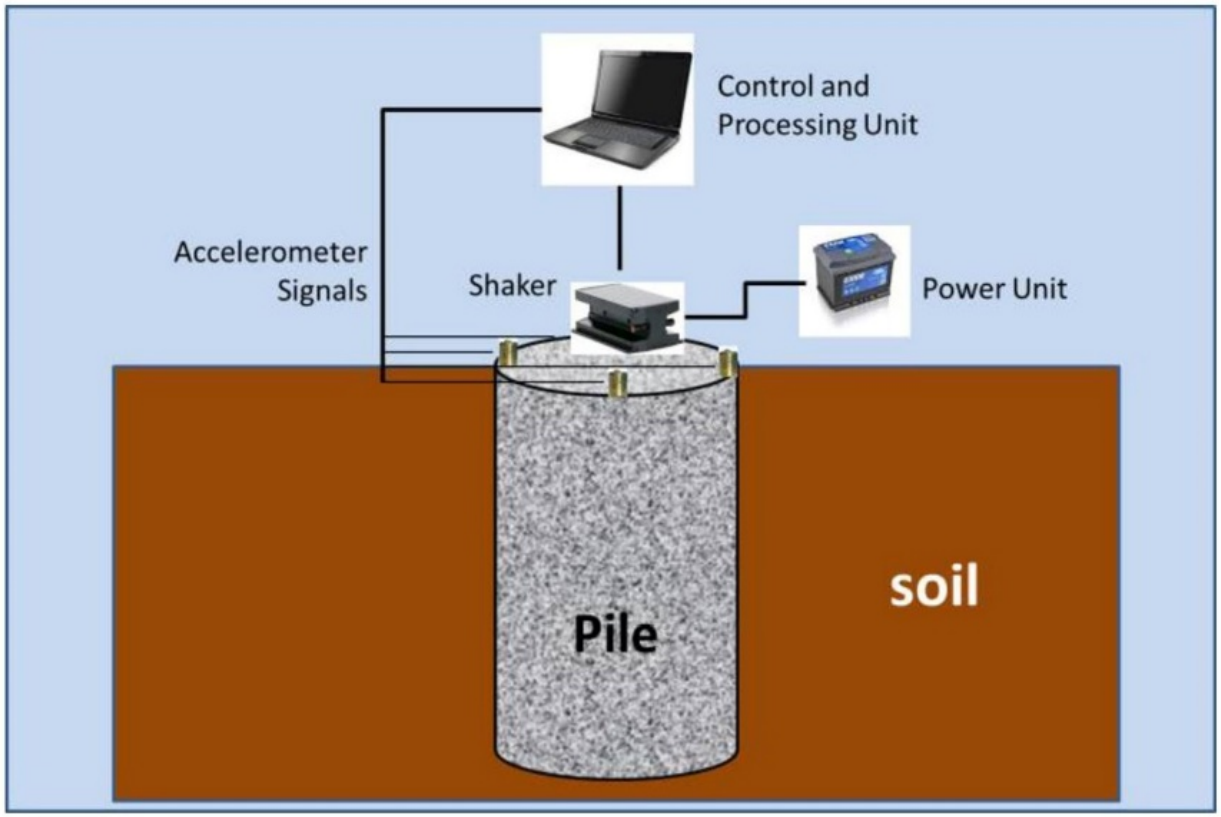
HARMONIC RESPONSE (PAQUET 1968)





PILEINSPECT (2013-2016)



Schematic diagram of PileInspect system

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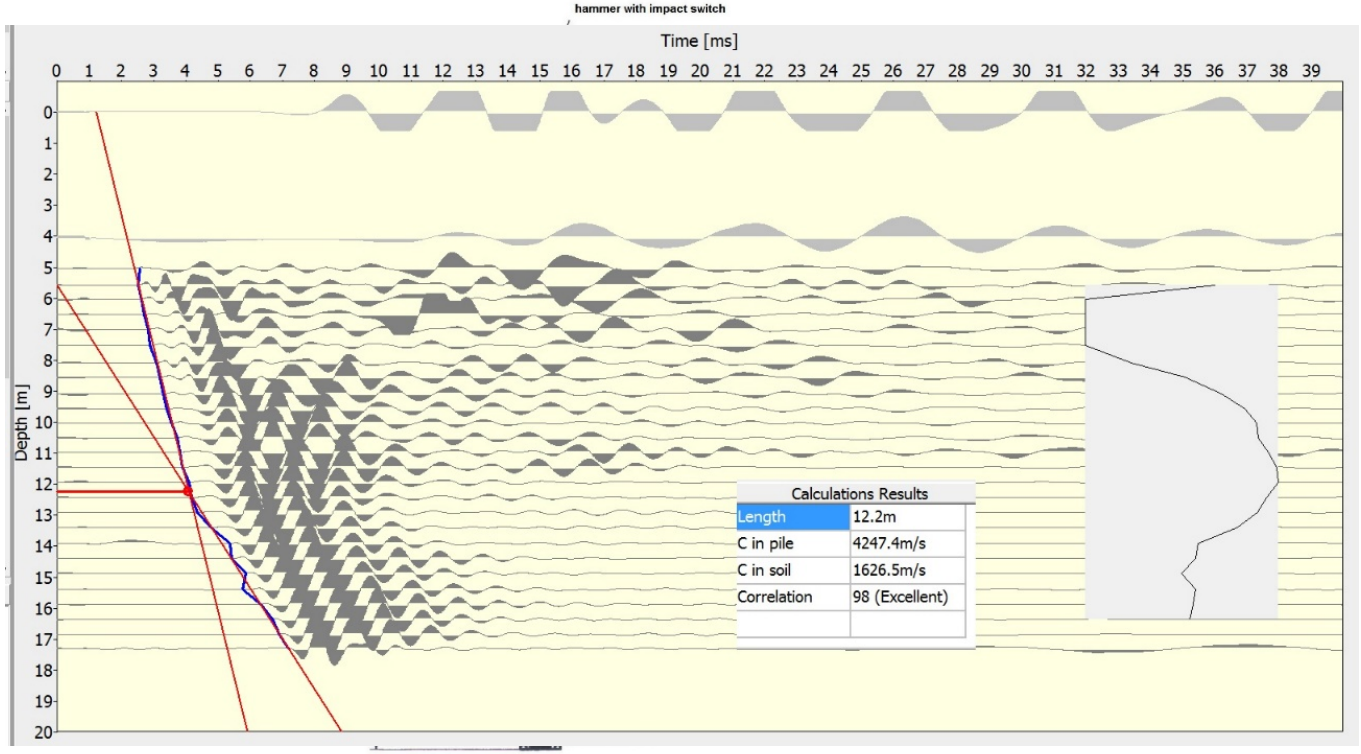
Parallel Seismic Testing



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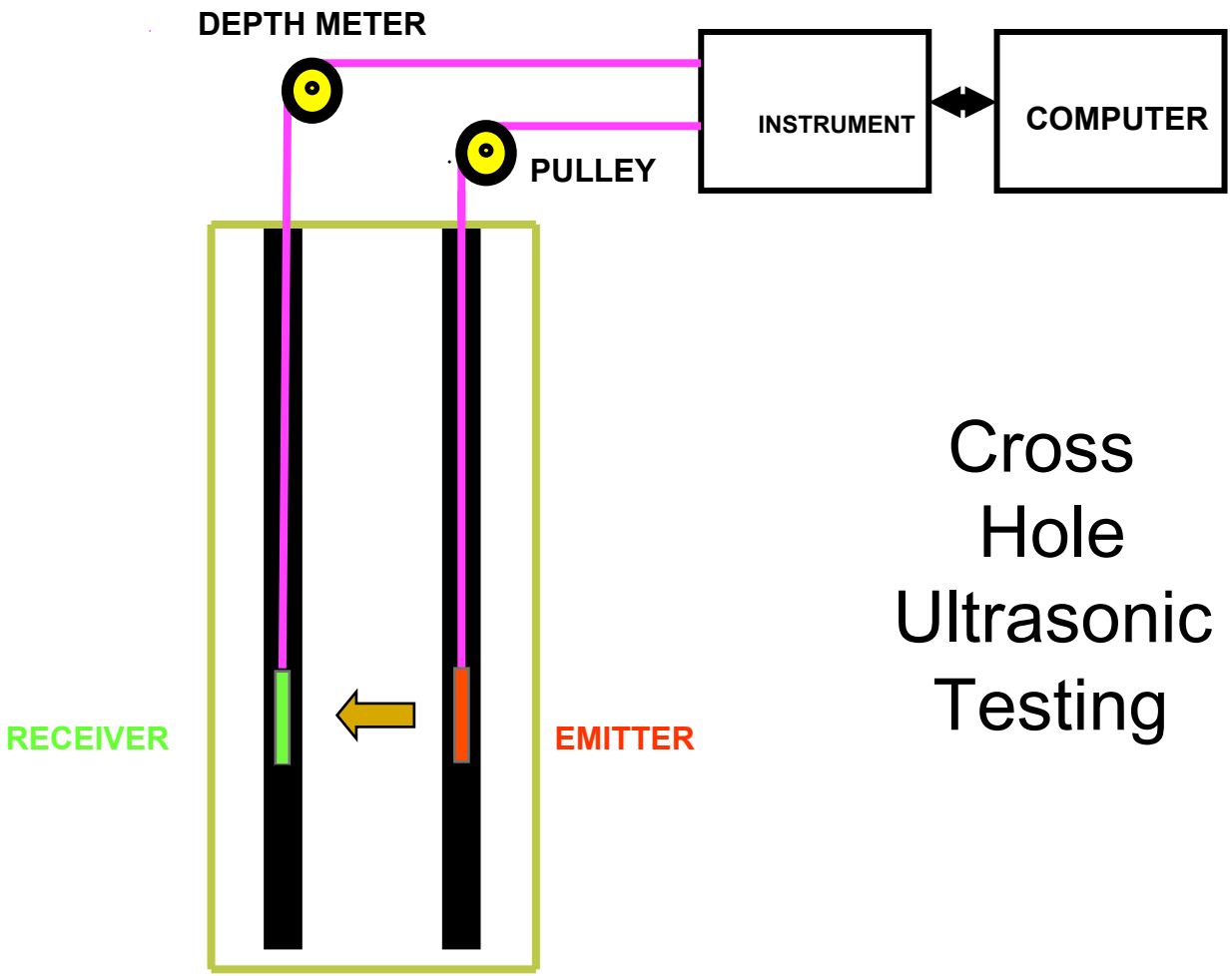

Cross Hole Ultrasonic Testing

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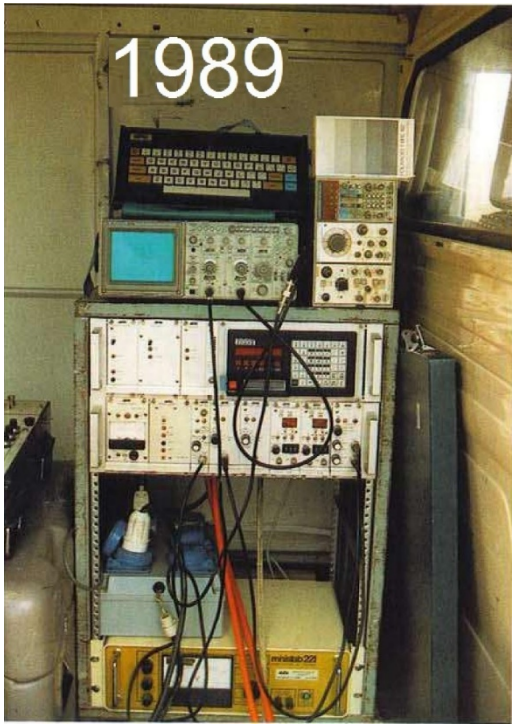
Cross hole ultrasonic equipment



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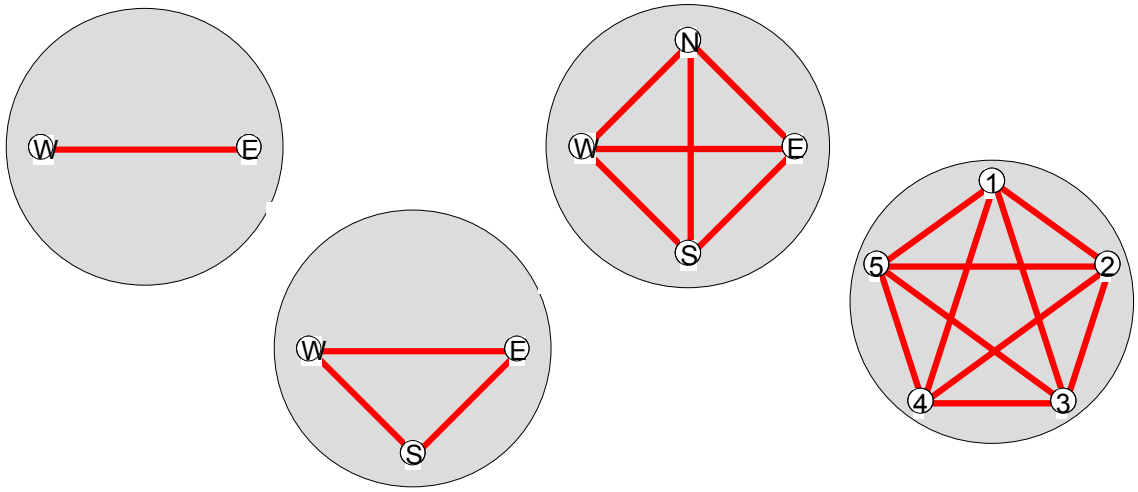
Access tube arrangement



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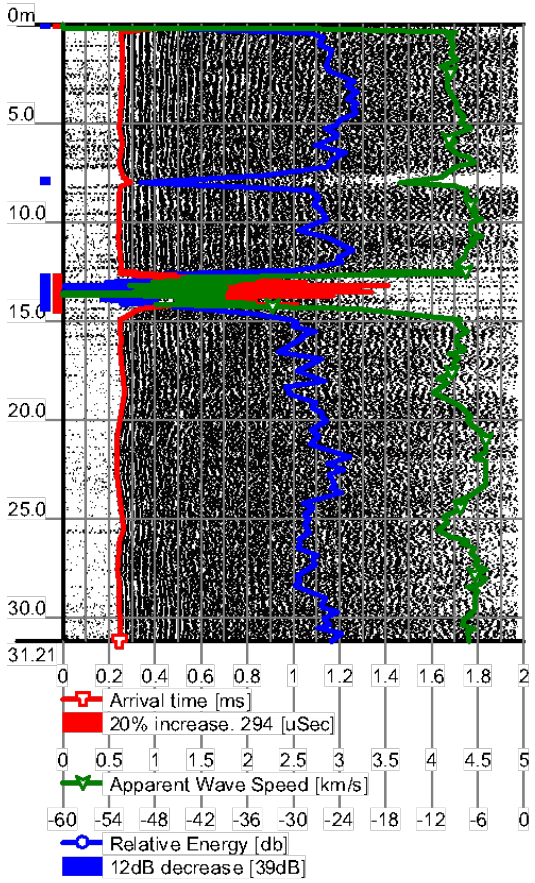
1-D output



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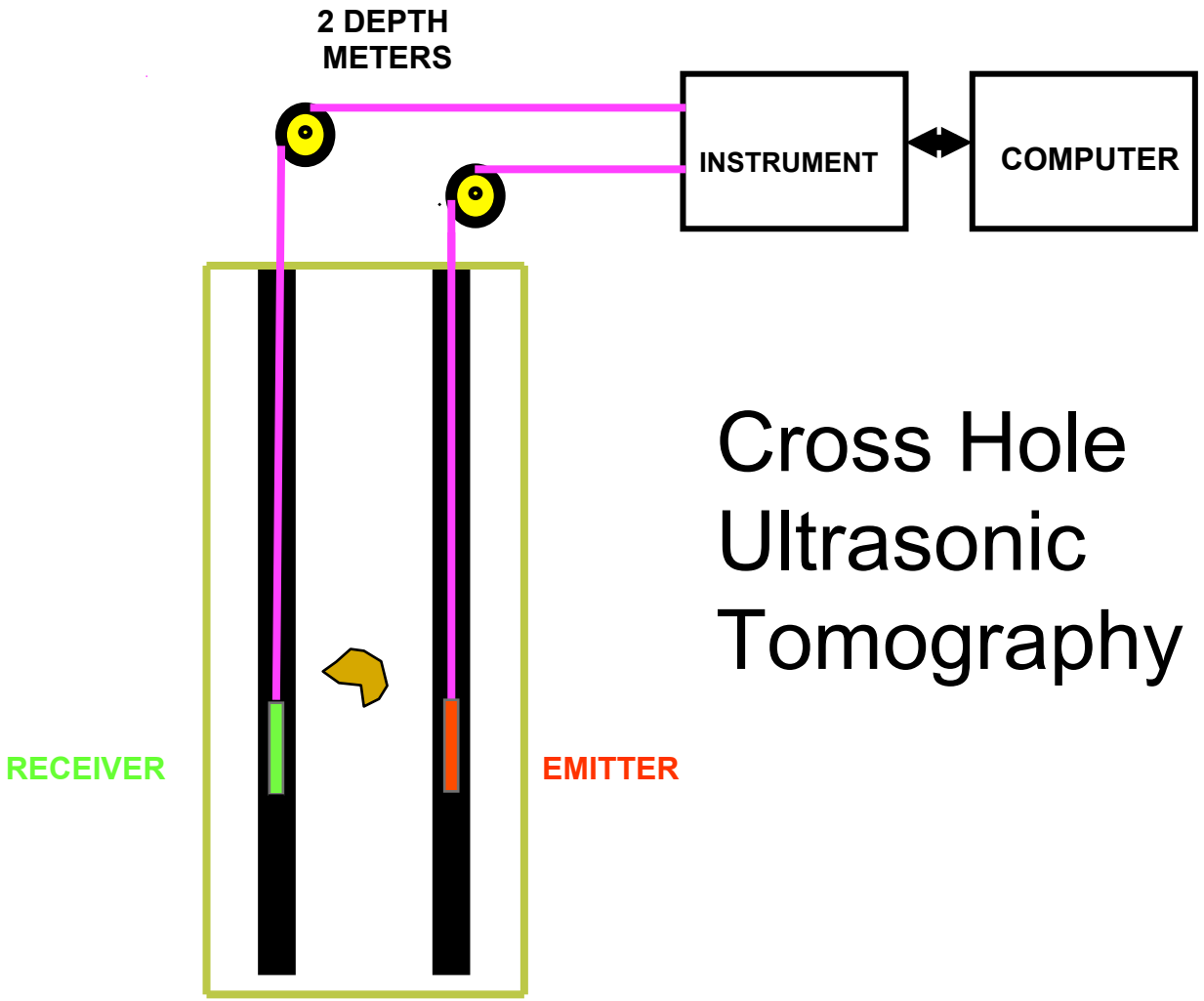

Cross Hole Ultrasonic Tomography

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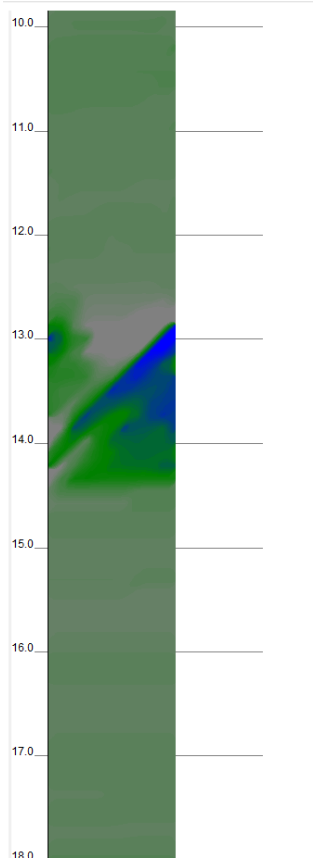
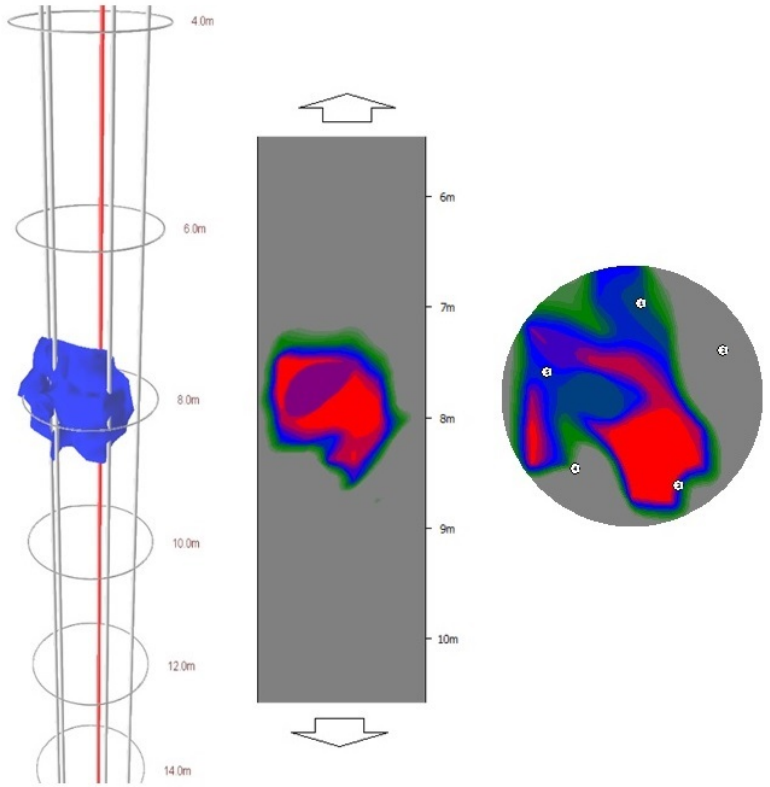
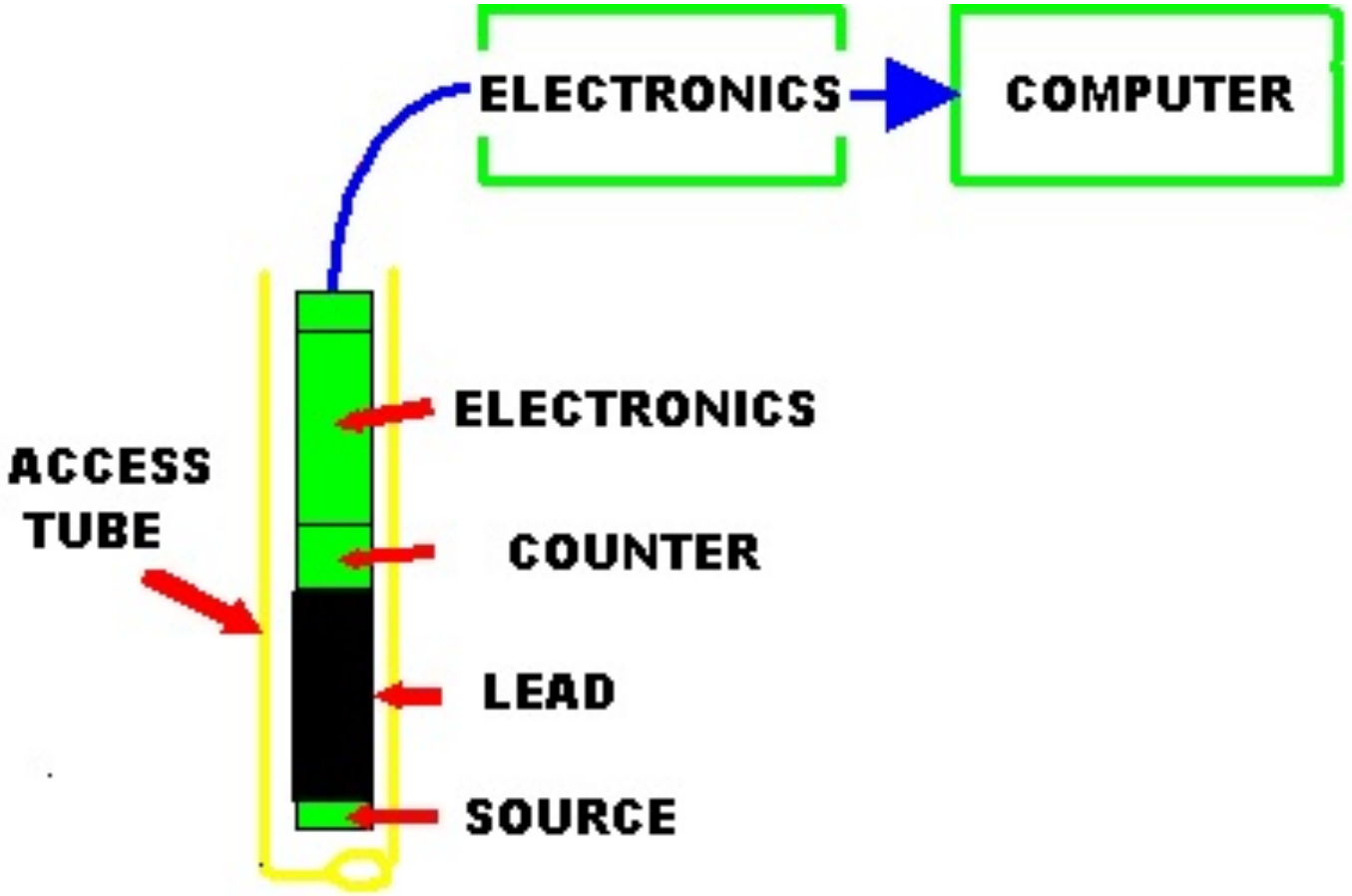

10.0
11.0
12.0
13.0
14.0
15.0
16.0
17.0
18.0

3DT


4.0m
6.0m
8.0m
10.0m
12.0m
14.0m
6m
7m
8m
9m
10m

2DT

Radioactive testing (Preiss 1971)



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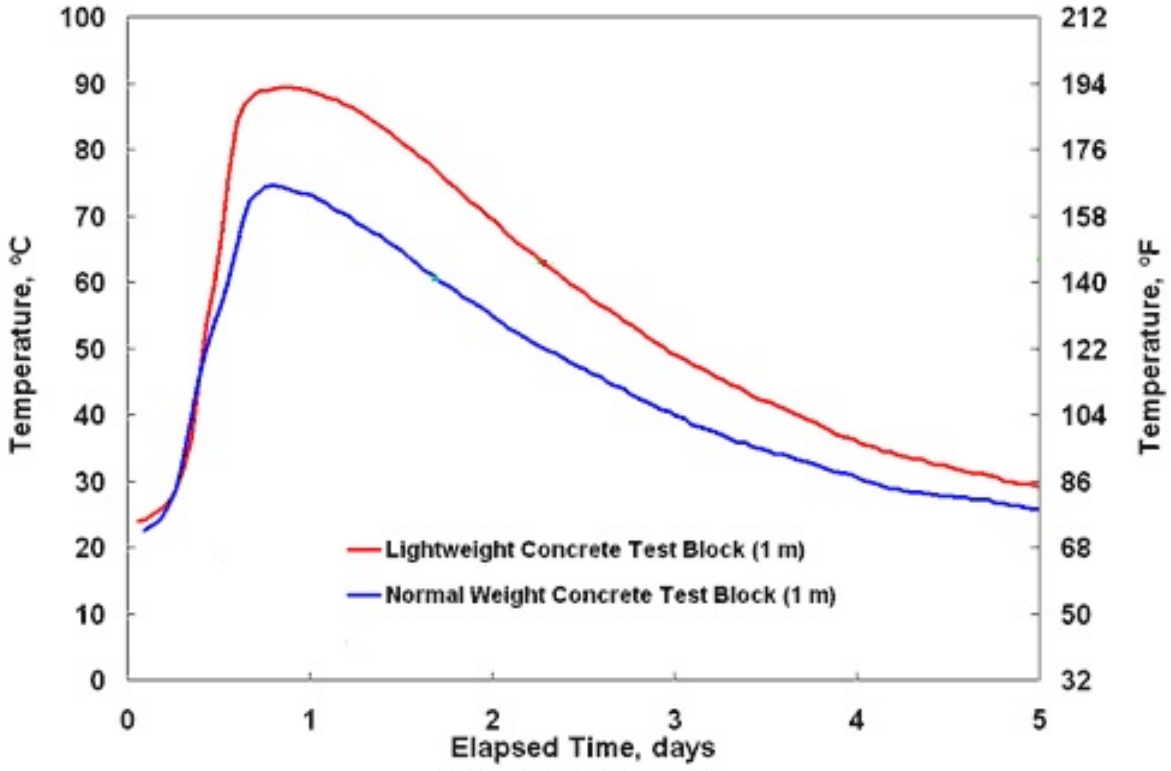
Thermal logging (2004)



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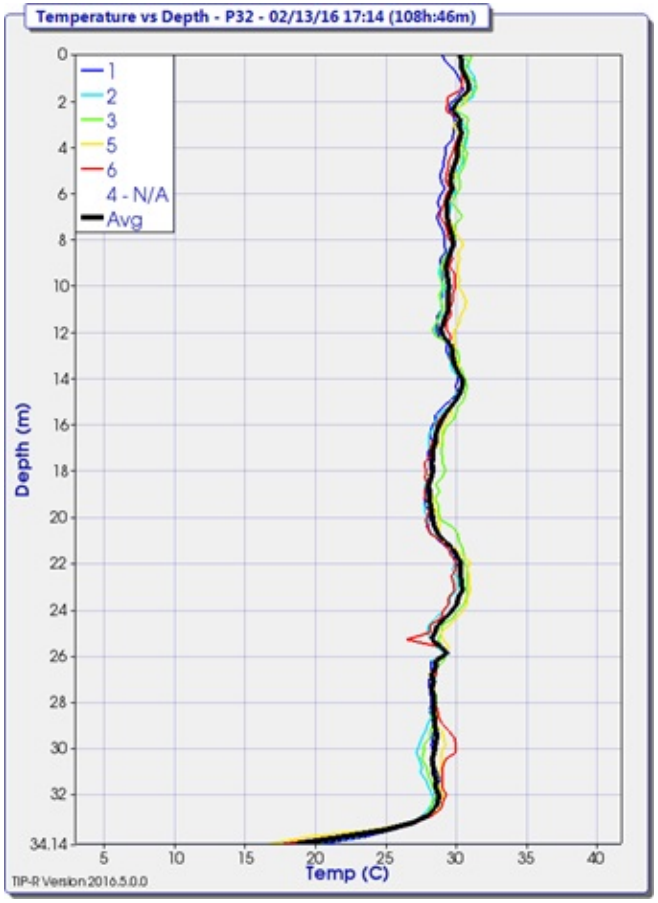

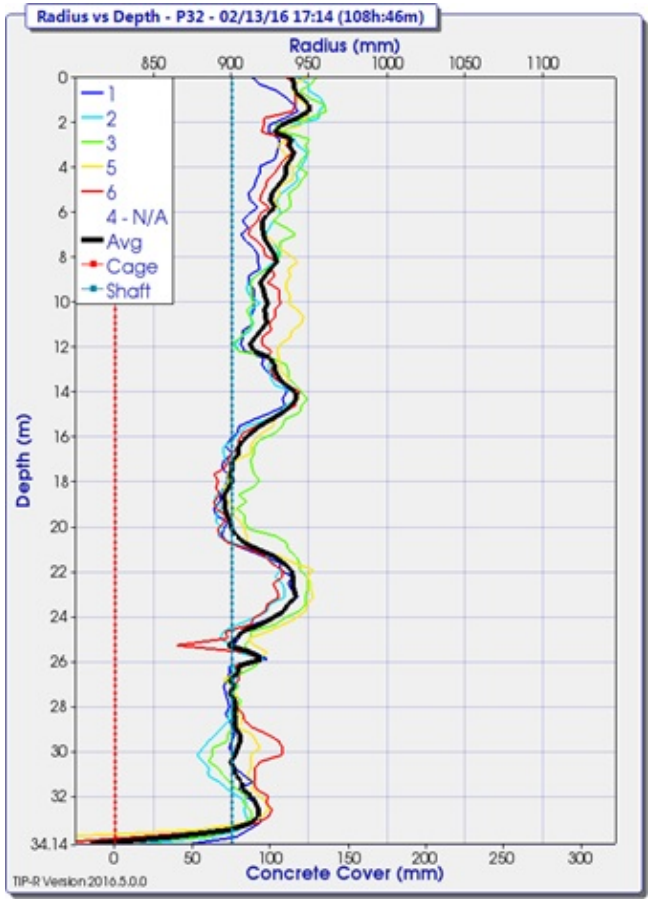

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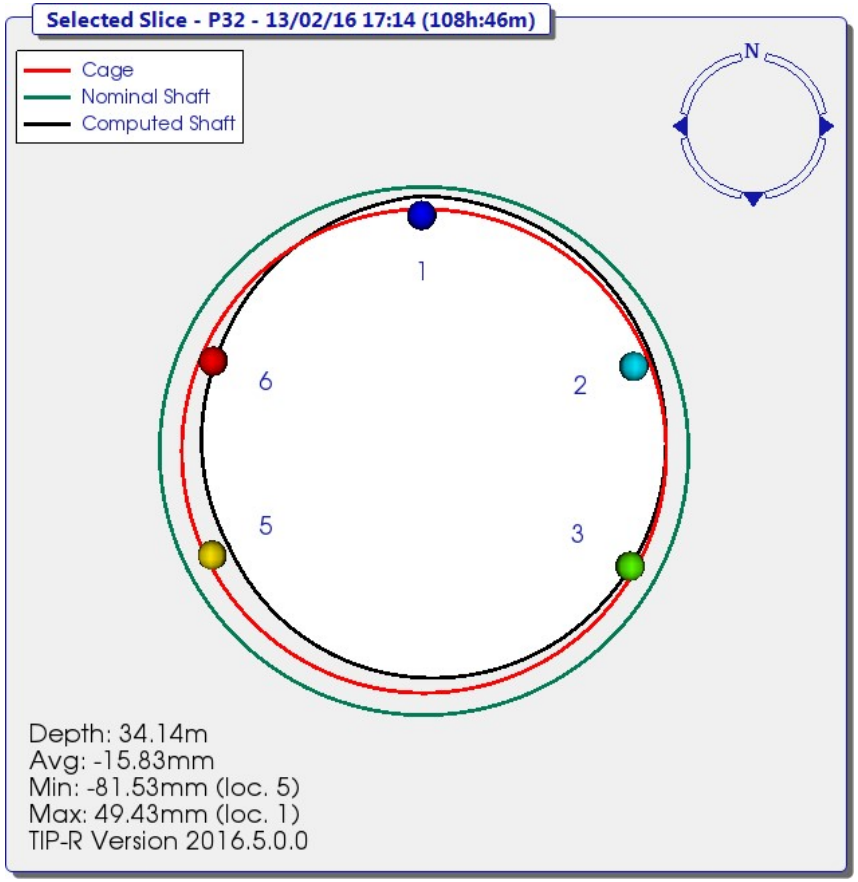
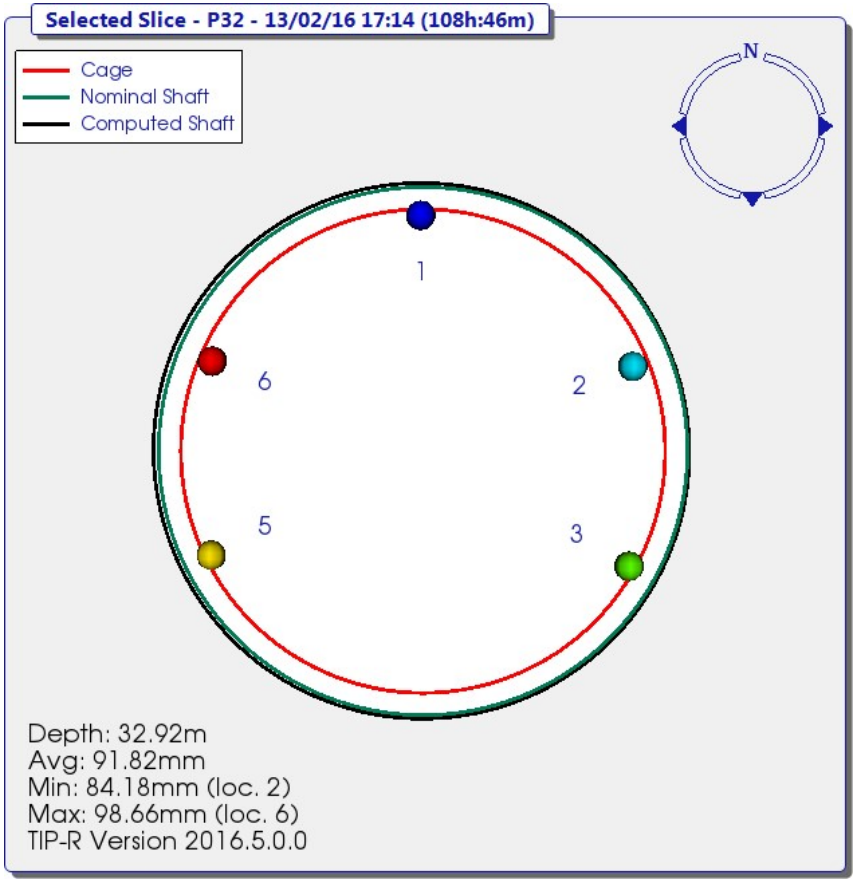
Slices





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PRESENT SITUATION

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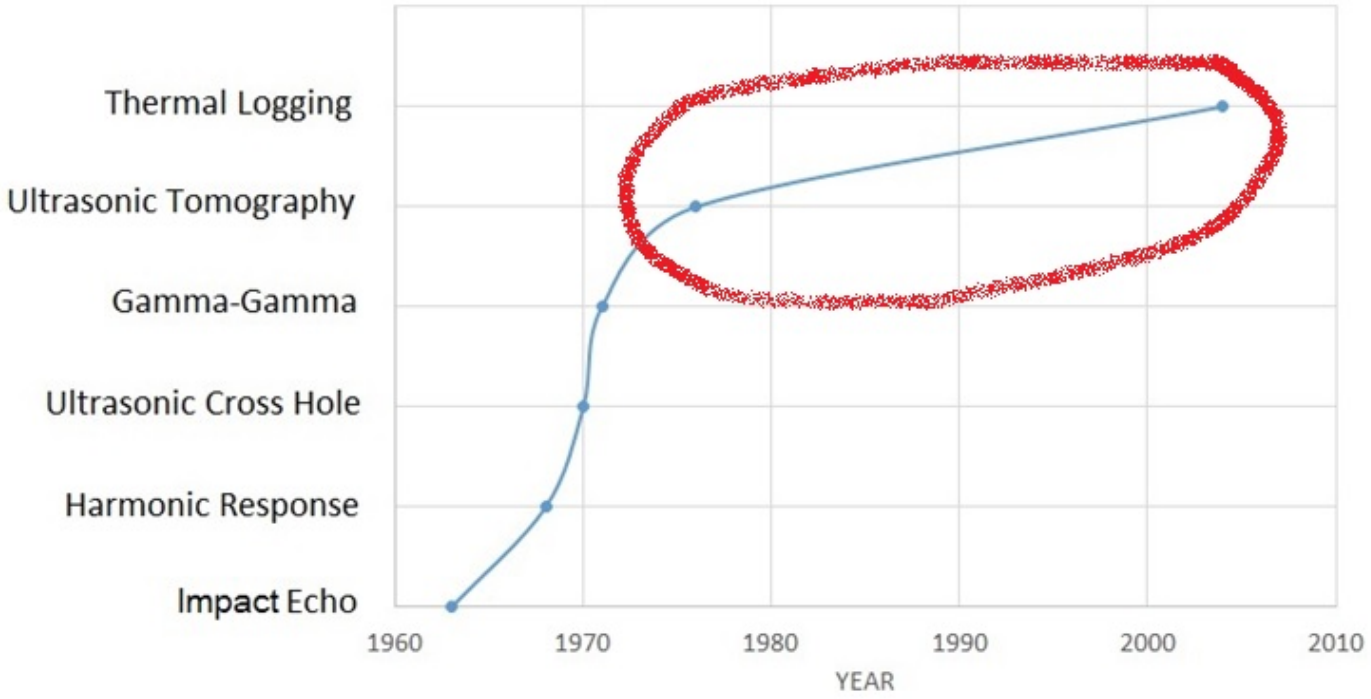
New development slowdown…



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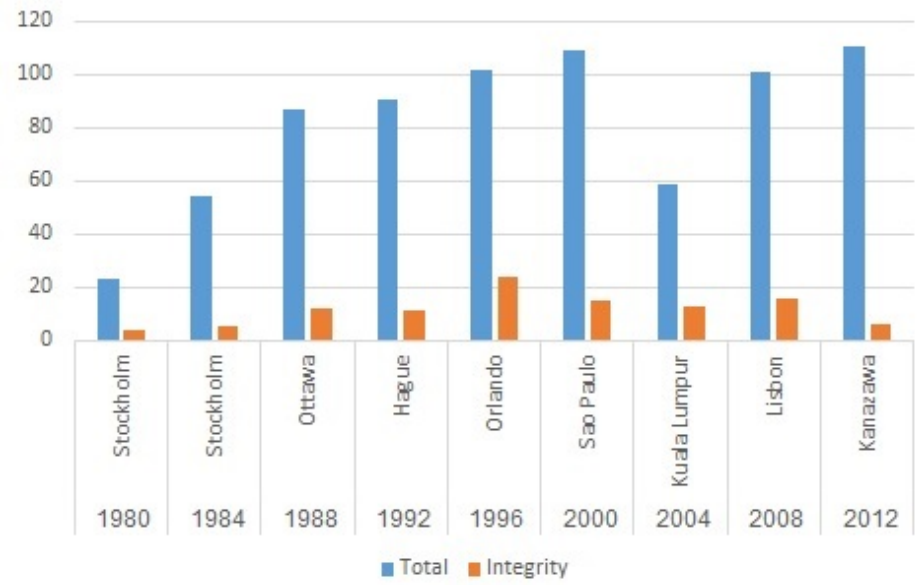
Integrity testing – a stagnant discipline?

Stress-wave conferences – number of papers



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We still stick to the 1-D wave equation that is based on the following assumptions:

- The pile is prismatic with a constant cross-section A, elastic with Young's Modulus E and homogeneous with mass density ρ
- Cross sections remain plane, parallel and uniformly stressed
- Lateral effects are negligible
- Soil properties are well-known

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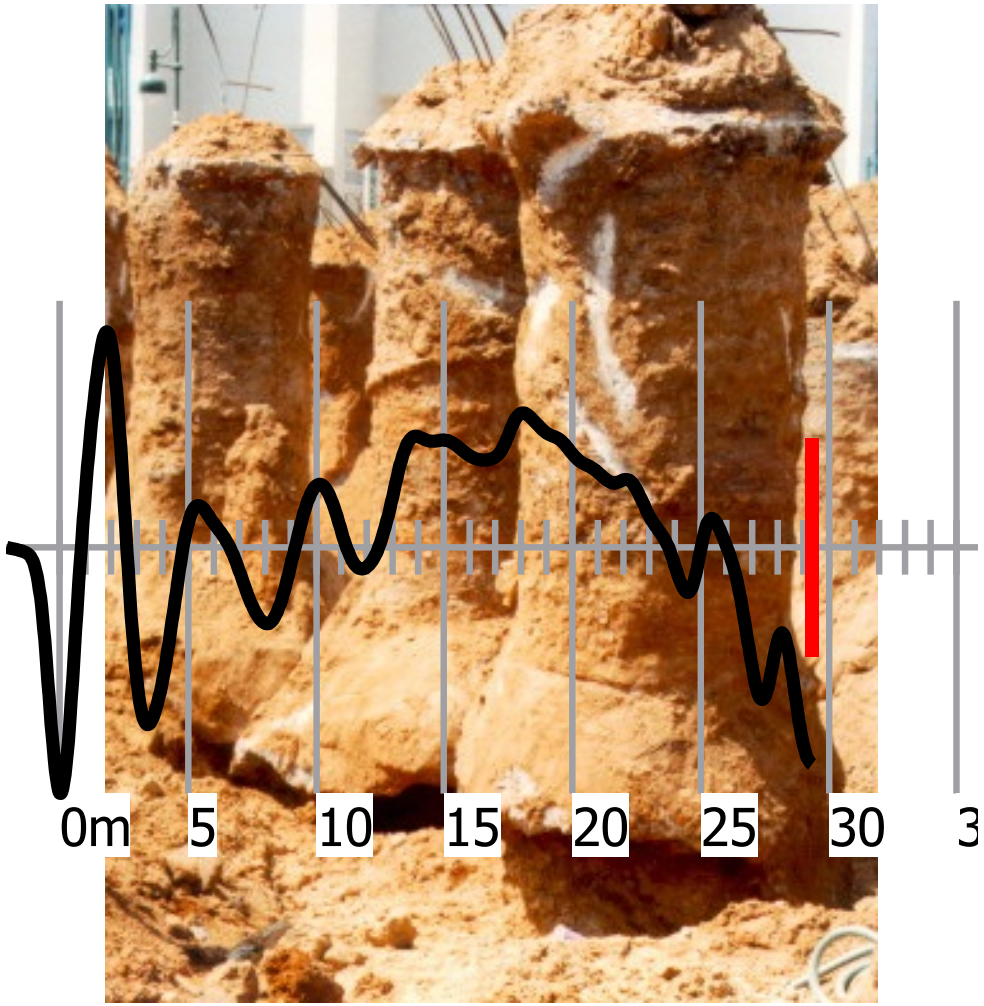
Wrong assumptions…

Lead to poor results!



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Future agenda

- Replace 1-D wave equation with FEM
- Integrate all the existing testing and analysis methods into a comprehensive data base with a common interface and standard CAD format
- Stamp every pile with GPS location & photo
- The exterior pile profile can be obtained from methods such as CFA monitoring, thermal logging or bored pile calipering.
- Interior mapping by ultrasonic tomography will serve as the first iteration of pile geometry.

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- Use data from the closest borehole log
- Where applicable, combine with the drawings of the superstructure
- Apply the input load at the application point and calculate displacements
- Input force can be static or dynamic, transient or steady state, axial or lateral, concentrated or distributed
- Modify pile geometry through evolutionary algorithm to find the pile geometry that will provide the best fit.

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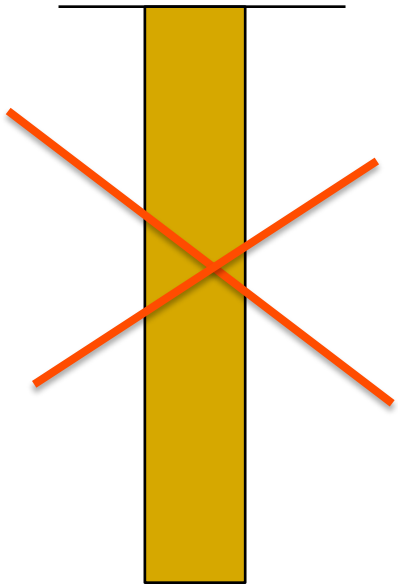

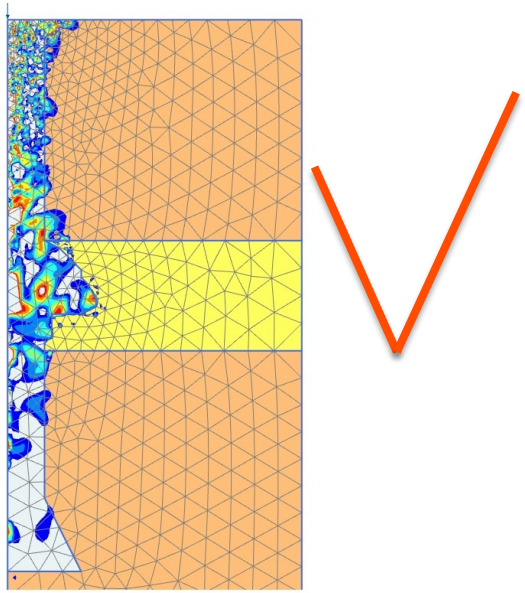

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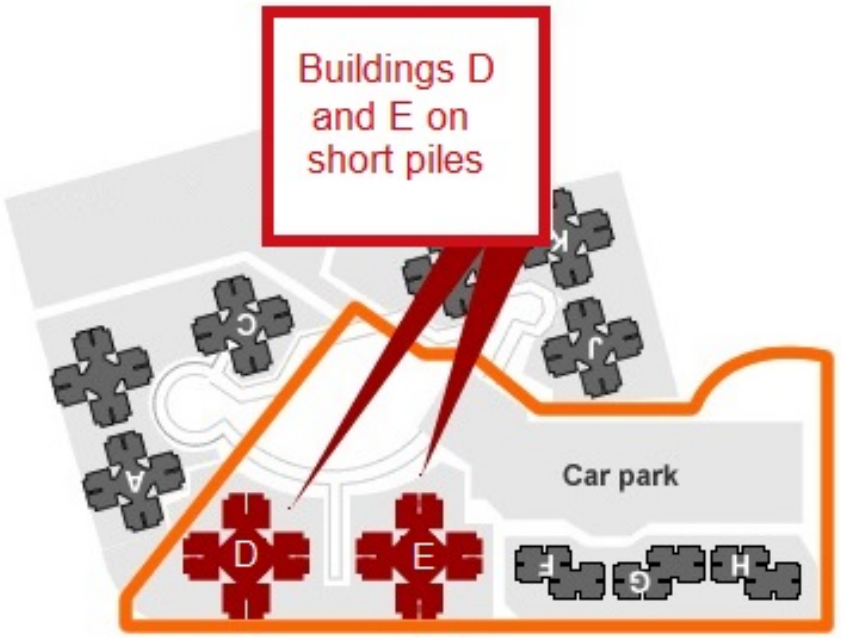
Yuen Chau Kok (Hong Kong) short pile scam 1999



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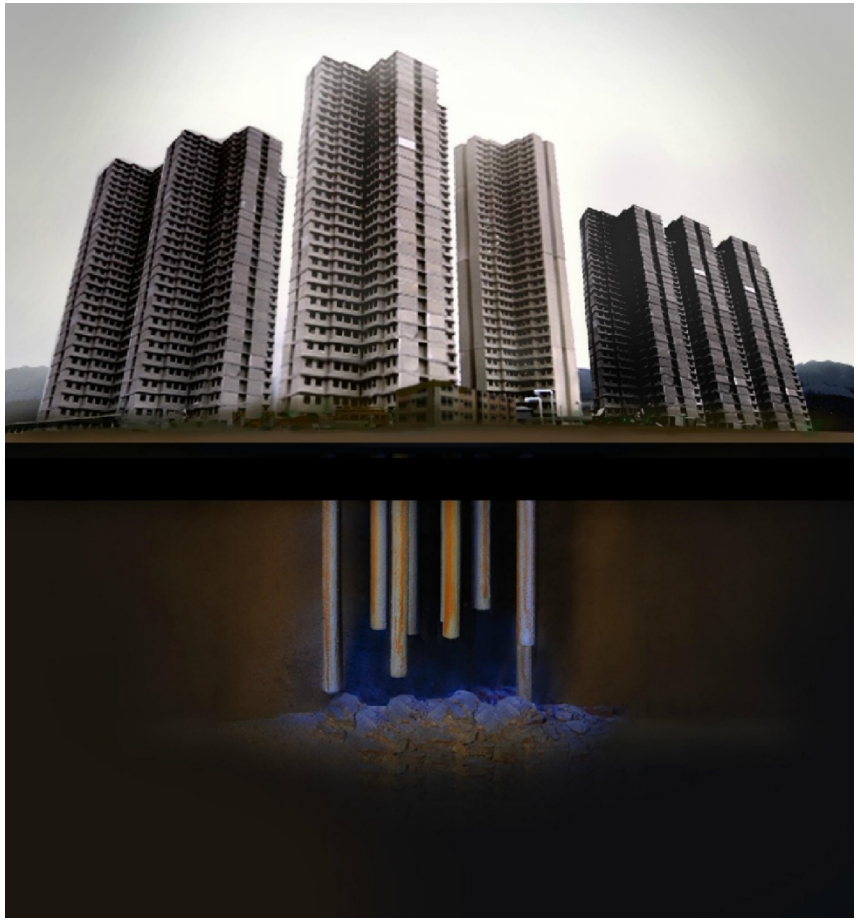

The buildings -

- The piles…

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The cover-up system

- Working at night when client's staff were absent
- falsifying site records
- diverting excess concrete to other projects
- blocking access tubes and replacing cross hole testing with harmonic response tests carried out on good piles

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The cover-up system (cont.)

- “doctoring” the tape measure used to check the depths
- replacing defective cores with good ones from other piles
- Etc. etc…

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Quis custodiant ipsos custodes?
(Juvenal)

or

Who will watch the watchmen?

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There is nothing new under the sun

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