Study on the nuclear method used in earthworks quality control of civil infrastructures

José Neves ¹, Cláudia Silva ², Ana Maria Duarte ²

¹ Department of Civil Engineering; University of Lisbon, Lisbon, Portugal ² Relacre-Isel, Lisbon, Portugal

Abstract: Compaction is essential in earthworks of civil infrastructures, such as dam embankments, building foundations, roads, and other transport infrastructures. The nuclear method is a non-destructive test that has been one of the most used field tests in the quality control of compaction for a long time due to its easy operation and accuracy. The technique uses nuclear equipment to measure soil and aggregates' moisture content and in-situ density. The fidelity of the method according to Portuguese technology is still unknown. The paper has two main objectives: (1) to describe the application of the non-destructive testing method to the quality control of compaction; (2) to present the repeatability and reproducibility of the method in its application to the case of soils based on proficiency tests. The paper presents the methodology followed in carrying out the proficiency tests and analysing the results related to the method's fidelity. The work points out the most critical aspects of the test and presents the repeatability and reproducibility related to in situ density and moisture content in the cases of direct transmission and backscatter measurements.

Keywords: civil engineering, quality control, Earthworks, Nuclear Method
Study on the nuclear method used in earthworks quality control of civil infrastructures

José Neves

CERIS, Instituto Superior Técnico, University of Lisbon
Study on the nuclear method used in earthworks quality control of civil infrastructures; José Neves (CERIS, Instituto Superior Técnico, University of Lisbon)
Some background...

**RELACRE** - Association of Accredited Laboratories of Portugal

Proficiency tests:

- Acoustic and vibrations
- Air and environment
- Heaters
- Electrical
- Water
- Food
- Textile
- Paper and paperboard
- Non-destructive tests
- Mechanical tests

**Technical Commission (since 2009)**

**CTR09 – Construction materials**

**Work Groups:**

- **WG1** – Concrete
- **WG2** – Aggregates
- **WG3** – Soils
- **WG4** – Asphalt concrete
- **WG5** – Field tests

Study on the nuclear method used in earthworks quality control of civil infrastructures; José Neves (CERIS, Instituto Superior Técnico, University of Lisbon)
Importance of the quality control of earthworks

Transportation (roads, railways, pipelines)
Buildings and bridges (foundations)
Embankment dams

- Resistance
- Deformability
- Permeability
- ...

Quality control

Density
Water content

Laboratory tests
Field tests

Study on the nuclear method used in earthworks quality control of civil infrastructures; José Neves (CERIS, Instituto Superior Técnico, University of Lisbon)
Traditional methods

**Laboratory tests**
- Proctor compaction method

**In-situ tests**
- Sand-cone method

- Bottle with calibrated sand
- Tap
- Excavation

Manual

Automatic
Non-destructive methods
Nuclear method – one of the most used in civil engineering

ASTM D6938

• Used in the control of compaction (density, water content)
• The principle of the nuclear method is based on the loss of radiation energy during the crossing of the medium being measured and which can be related to the properties associated with compaction: water content and density
• The measurement of water content is based on the transformation of fast neutrons emitted, with a certain energy, into slow neutrons after collision with hydrogen atoms in the soil.
• In measuring the wet density of the soil, the nuclear method uses gamma radiation. The relationship between the radiation emitted by the emitting source, with a given energy, and the radiation received at the receiver can be associated with soil density.
• The equipment can be operated in two modes: surface measurement (backscatter mode) and depth measurement (direct transmission mode)
Background
Past publications

Study on the nuclear method used in earthworks quality control of civil infrastructures; José Neves (CERIS, Instituto Superior Técnico, University of Lisbon)
Objectives

Two main objectives:

1. Describe the application of the non-destructive testing method – Nuclear method – to the quality control of compaction

2. Present the repeatability and reproducibility of the method in its application to the case of soils based on proficiency tests
Methodology

Proficiency tests - ISO/IEC 17043

Years
2010 | 2012 | 2013 | 2015 | 2019 | 2022

5 PT Schemes
12 years

Organization
• RELACRE
  Association of Accredited Laboratories of Portugal

Collaboration
• University of Lisbon – Instituto Superior Técnico
• Portuguese Air Force
Methodology

Proficiency tests - ISO/IEC 17043

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>Section</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>A</td>
<td>D</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>L2</td>
<td>B</td>
<td>E</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>L3</td>
<td>C</td>
<td>F</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>L4</td>
<td>D</td>
<td>H</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>L5</td>
<td>E</td>
<td>I</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>L6</td>
<td>F</td>
<td>G</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>L7</td>
<td>G</td>
<td>C</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>L8</td>
<td>H</td>
<td>B</td>
<td>G</td>
<td></td>
</tr>
</tbody>
</table>

Operating mode
Measurement depth (direct transmission mode)
Number of measurements
Duration and interval between measurements
Results and discussion

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Operating mode</th>
<th>Test</th>
<th>Xx</th>
<th>SDx</th>
<th>Repeatability</th>
<th>Reproducibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet density (kg/m³)</td>
<td>Direct transmission</td>
<td>EAp_1</td>
<td>2004</td>
<td>34.9</td>
<td>6.1</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EAp_2</td>
<td>2078</td>
<td>47.5</td>
<td>8.4</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EAp_3</td>
<td>2142</td>
<td>38.7</td>
<td>6.3</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EAp_4</td>
<td>2041</td>
<td>37.4</td>
<td>63.3</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EAp_5</td>
<td>2051</td>
<td>23.7</td>
<td>28.7</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EAp_6</td>
<td>2057</td>
<td>27.3</td>
<td>31.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Moisture content (%)</td>
<td>Backscatter</td>
<td>EAp_1</td>
<td>2015</td>
<td>59.6</td>
<td>10.8</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EAp_2</td>
<td>1969</td>
<td>89.0</td>
<td>14.6</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EAp_3</td>
<td>2197</td>
<td>80.3</td>
<td>10.0</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EAp_4</td>
<td>2015</td>
<td>50.7</td>
<td>62.5</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EAp_5</td>
<td>1956</td>
<td>84.8</td>
<td>82.2</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EAp_6</td>
<td>1921</td>
<td>71.5</td>
<td>56.2</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Legend:
Xx – Mean
SDx – Standard deviation
SDr – Standard deviation of repeatability
SDR – Standard deviation of reproducibility
CVr – Coefficient of variation of repeatability
CVR – Coefficient of variation of reproducibility
r – Limit of repeatability
R – Limit of reproducibility
Conclusions

The main conclusions of the work are:

✔ The adequacy of the nuclear method was confirmed
✔ In general, there was some variability in the repeatability of the test, with the less satisfactory behaviour observed for reproducibility.
✔ The results were different depending on the operating mode of the equipment.
✔ The wet density measurements taken at depth (direct transmission mode) showed better repeatability and reproducibility than at the surface (backscatter).
✔ In the case of the water content, the fidelity of measurements was independent of the measurement method.
Study on the nuclear method used in earthworks quality control of civil infrastructures

Thank you very much | Muito obrigado