Quality control in Deep Soil Mixing
State of the Art
Deep soil mixing: Called as well « Deep Cement mixing » in Asia
Mechanical mixing of the in-situ soil with an hydraulic binder
Goal is to create soil cement material with improved properties
Geometry of the volume of treated soil is given by the geometry of the tool and its motion

There are globally two means of incorporating the binder:
- either as a powder => Dry method
- or as a liquid (binder + water + additives –if needed -) => Wet method

This presentation focuses on wet method, as it represents the majority of the applications

Reminder: QC/QA programme as per DFI Guidelines

A good QC/QA Program Plan will indicate how construction parameters will be determined prior to beginning the production work, how those parameters will be monitored, recorded, and reviewed, how deficiencies observed during review of the construction records will be addressed, and how the results of the quality assurance testing will be used to modify construction parameters being used on a real time basis to suit conditions encountered.
## Summary

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Preliminary lab trials

European Standard EN 14679

Execution of geotechnical works only
Very few information about preliminary lab trials.
Lab trials are specified to be mandatory if the construction company cannot justify having treated similar soils with similar construction conditions


Bench testing may be performed by the Owner prior to bidding a project to establish the feasibility of using DMM and/or to provide the DMM Contractor with an indication of the binder amounts required. Alternately or additionally, the DMM Contractor may choose to perform bench testing after being selected to perform the work to provide an initial estimate of the binder required to meet the project acceptance criteria.

Our practice

Lab trials mandatory in any case with presence of organics or contamination
Could be optional if enough experience with the binder in similar ground conditions
Positioning and Verticality

Embedded GPS positioning is progressively implemented. Accuracy: 2-3 cm
No GPS precise on trenchers for the time being

Verticality measurement:
- With 2 no of inclinometers for CSM
- With inclinometer + azimuth for DSM
- Automatic verticality of blade with trencher

Verticality as well as GPS coordinates are shown on reports
Grout properties

On daily basis, rheology of the treatment grout is controlled:
- Specific gravity (mandatory)
- Additional Marsh funnel viscosity (in presence of bentonite or other additives)

Regularly, samples of grout are taken for UCS testing in laboratory. Usually tests are done at different curing times: 7 / sometimes 14 / 28 days.
**Construction Parameters**

All deep mixing rigs are equipped with a full set of sensors.

Equipment parameters: hydraulic pressures (torque), rotation speed, rate of penetration, depth, verticality, GPS, …

Additional parameters: engine parameters (CANBus), …

Grout parameters: flow-rate, pressure, specific gravity

Mixing factor (Blade Rotation Number) and Grout volumes are computed in real time.

At a minimum, these 2 parameters are displayed.

**Real time display at distance**, on mobile devices or computer in site office

Once treatment is achieved, **data are transmitted wireless** (GPRS / Radio / Wifi / Bluetooth)

Automatic data processing. Reports are issued immediately
As built 3D models

Geomix Caissons against liquefaction
Benhamou and al. - ISSMGE - TC 211 International Symposium on Ground Improvement IS-GI Brussels 2012

Ground Treatment by Combination of CSM and Jet-Grouting in Hong Kong

Design and construction aspects of deep soil mixing of soft alluvium and peat across the proposed King Edward Memorial Park Foreshore work site
Talby and al. - DFI – Deep Mixing Conference, Gdansk, 2020
Wet grab sampling

Wet grab sampling consists in taking samples of the fresh soil cement mixture at depth.

Samples are casted on site in cubes or cylinders, then stored on site for a proper curing.

Then samples are transferred to a lab for testing.

The sampled material must be representative of the in situ mixture.

When doing samples, coarser elements (bigger than 1/5th of the sample dimension) can be removed when casting to avoid early breaks when testing.
Non destructive controls

Pumping tests
Excavations

Ultrasonic Wave velocity measurement
Influence of mixing and curing conditions on the characteristics and durability of soils stabilised by deep mixing
Guimond-Barrett, PHD report, University of Le Havre, France, 2013
Destructive controls

Coring through the deep soil mixed mass is usually applied

- Needs to be done by trained operators + double/triple core barrel to get samples for testing
- Very difficult when compressive strength is below 1MPa

In situ permeability testing in mass treatment

Coring

Deep soil mixing in soft and weathered chalk
Mathieu and al, Deep Mixing 2020, Gdansk
Destructive controls

In situ permeability testing in “thin” cutoff wall may be not representative of the quality of the works done.

Sample taken in depth during the execution of the cut off is usually more representative due to:

- Risk of deviation
- Risk of fracturing the soil mixed i.e. change of permeability
- Difficulty to define which ground water table to take into account (which side?)
- …
## DFI soil mixing guide

### Minimum Wet grab sample and core sample frequencies

<table>
<thead>
<tr>
<th>Application</th>
<th>Wet Sample</th>
<th>Strength Tests on Wet Samples</th>
<th>Permeability Tests on Wet Samples</th>
<th>Core Sample with Visual Inspection</th>
<th>Unconfined Compressive Strength on Core Sample</th>
<th>Visual Inspection of Wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporary Earth Retention Wall</td>
<td>One wet sample per day (cast six (6) 3-inch x 6-inch cylinders (specimens) from each wet sample)</td>
<td>Test 2 specimens at 7 days</td>
<td>Test 1 sample or every 40,000 SF of wall, whichever is greater</td>
<td>None</td>
<td>None</td>
<td>Daily during excavation</td>
</tr>
<tr>
<td>Permanent Earth Retention Wall</td>
<td></td>
<td>Test 2 specimens at 28 days</td>
<td>Test 1 sample per project or every 10,000 SF of wall, whichever is greater</td>
<td>None</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Permanent Water Cutoff</td>
<td></td>
<td>Reserve 2 specimens</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permanent Ground Improvement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

- Test 3 samples at 28 days Reserve 2 specimens
Load testing

Load test on deep soil mixing column (in lab)
Real-scale tests on soilmix elements
Denies and al, 2014

Load test on deep soil mixing column (on site)
Underpinning works under shallow foundations in Blaj, Romania using Springsol technology
Magureanu and al, XVI Danube European Conference on Geotechnical Engineering, 2018
Big data

Central database

- Production records
- Tests records
- Ground investigation reports
- As built models
Thank you