Deep Soil Mixing (DSM)
Improvement of weak soils by the DSM method
Deep Soil Mixing

The Deep Soil Mixing method (DSM) was invented in Japan and Scandinavia and subsequently further developed by Keller. Its use in strengthening and sealing weak and permeable soils is growing around the world. The technique leads to significant improvement of the mechanical and physical properties of the in-situ soil, which is mixed with cement or compound binders to form the so-called soil-mix (or soil-cement). The resulting stabilised soil material generally has a higher strength, lower permeability and lower compressibility than the original soil. Although the DSM technology is based on simple principles it requires, on the one hand, significant experience and expertise in relevant planning stages, involving soil-mix and geotechnical design, and execution. On the other hand it also requires the use of specialised rigs and mixing tools to meet specifications imposed by ongoing quality assessments and performance monitoring procedures.

Wet and Dry mixing

Basically there are two different mixing methods. The existing soil to be improved can be mixed mechanically either with a slurry incorporating a binder (wet DSM) or with a dry binder (dry DSM). Slurry jetting can be also used to enhance mechanical mixing. The wet method is more appropriate in soft clays, silts and fine-grained sands with lower moisture content and in stratified ground conditions including interbedded soft and stiff or dense soil layers. The dry method is more suitable for soft soils with a very high moisture content, and hence appropriate for mixing with dry binders. Stabilisation of organic soils and sludges is also possible, but is more difficult and requires carefully tailored binders and execution procedures.

Advantages of Technology

DSM technology is based on a stimulating concept of improving natural soils or brownfield subgrade to match adopted design requirements, thus eliminating problematic excavation and replacement or more expensive deep-foundation methods. The broad range of applications and variable patterns of execution of soil mixing columns allow safe and very economical ground-engineering solutions. The use of non-toxic binders as soil additives, including industrial by-products, and the reduction in spoil volumes comparing with jet grouting or classical drilled piles, for example, firmly position DSM as an environmentally friendly technology. The execution and quality control of DSM works are carried out in accordance with European standard EN 14679.

Key benefits

- economical
- vibration free
- flexible in application
- reduces construction time
- environmentally friendly

Typical Applications

- Embankments on soft soils
- Support of strip, pad and slab foundations
- Bridge and wind-turbine foundations
- Excavation protection walls using reinforced columns
- Slope stabilisation
- Mitigation of liquefaction potential
- Cut-off walls and barriers
- Incapsulation and immobilisation of pollutants

Examples

Installation of a cut-off wall in a dike – Germany

Construction of a pit wall in Austria

Protection of deep excavation in Poland

Deep Soil Mixing in reclaimed area in Singapore
The wet DSM method
Mechanical wet deep soil mixing

In Keller’s deep soil mixing method a special mixing tool is inserted into the in-situ soil. This mixing tool comprises a drilling rod, transverse beams and a drill end with a head. The drilling is vibratio-free, and is assisted by cement slurry outflow from nozzles positioned at the end of the soil auger. Once the design depth is reached, the construction phase of DSM columns commences. Basically the diameter of such columns ranges from 40 to 240 cm, depending on the application.

The mixing tool, which may also move up and down along the column length to improve the homogeneity of the soil mix, assures thorough mixing of the slurry with the soil. The composition and volume of injected slurry is adjusted to achieve the properties required of the stabilised soil, taking into account the required strength and/or sealing functions. Tightness may be further enhanced by adding various components to the slurry, such as bentonite. The bending stiffness of DSM elements can be improved with steel reinforcement inserted into fresh columns. Wet DSM is also possible inside a tube. This method, called Tubular Soil Mixing (TSM), is mainly used for execution of high-quality columns applied for excavation control.

Slurry nozzles can be positioned on the main string or along mixing blades

Slurry can be injected during the penetration and withdrawal phases, the amount being varied depending on soil conditions
Quality Control
QC and QA are obtained from the column-installation protocols and the results of relevant laboratory and field-verification tests. Each column is provided with a chart-log, which comprises: date and time of execution, length of column shaft, penetration/withdrawal rates of the mixing tool, mixing speed, pressure and flow rate of pumped slurry, total slurry consumption per column. Specimens of stabilised soils for testing are usually obtained from fresh columns with the wet grab method. Advanced core drilling and other field-testing methods can also be used to obtain specimens and to inspect continuity, uniformity and stiffness of DSM columns. The selection of suitable verification methods depends on their relevance, accuracy and applicability in relation to the purpose and pattern of soil treatment and strength of the stabilised soil.

Design
Planning of soil mixing involves the assessment and selection of the engineering properties of stabilised soil in specific ground conditions (soil-mix design), and the selection of the installation pattern and geometry of improved ground (geotechnical design). The expected compressive strength of the stabilised soil is usually selected in relation to the physical and chemical characteristics of the treated soil and the groundwater, the type and amount of cement and other relevant working specifications, such as the water/cement ratio and the applied mixing work. The purpose of geotechnical design is to determine the final installation pattern and geometry of improved ground on the basis of appropriate stability and settlement analyses to satisfy the functional requirements of the supported structure.

Exposed DSM columns

Typical mixing tools used for wet DSM method

Examples of DSM column patterns

Exposed DSM columns for a bridge support

Exposed cut-off wall with secant DSM columns
In contrast to the wet method, dry soil mixing is only possible in soils that have sufficient moisture content to allow chemical reaction with the soil and groundwater of stabilising binders injected in dry form. The basic advantage of dry mixing is that stabilisation effects can be obtained in deep deposits of very weak soils, including organic soils, with high productivity, almost no spoil and low cost. In addition, operations at low temperatures are possible.

Typical equipment for dry DSM comprises stationary or mobile binder storage and feeding plant and a purpose-designed drilling rig for installation of the columns, equipped with special mixing tool at the end of the mixing rod.

Typical column diameter is 60 to 80 cm, and the depth of treatment is up to 25 m. Charging and mixing of dry binder with soil takes place while the rod is withdrawn, and the mixing tool is rotated in the opposite direction to that of the penetration phase. The binder is transported from the shuttle to the rig through connecting hoses using compressed air. Binder quantity is adjusted by changing the rotation speed of the feed wheel. Air pressure and the amount of binder are automatically controlled to supply the specified dosage of binder to the treated zone of soil. As a rule plastic clays and silts are strengthened by lime, or cement with lime, while in organic soils mixes containing blast-furnace slag are used.
Quality Control
As with DSM columns constructed with the wet method, quality control and testing are conducted both during execution and after completion of works. Each column is provided with a chart-log printed by an automatic recording device. Upon completion of works control tests are carried out pursuant to assumptions adopted in the design. Standard tests involve mainly probe testing. They are feasible in columns designed for lower strength, and include Modified Cone-Penetration Tests and Pullout-Resistance Tests to avoid the problem of the cone’s tendency to wander out of longer columns. Laboratory tests on specimens extracted from exposed columns can also be carried out, if required.

Mass Stabilisation for shallow mixing
Shallow dry mixing offers a cost-effective solution for ground improvement works or site remediation when dealing with substantial volumes of very weak or contaminated superficial soils with high water content, such as deposits of dredged sediments, wet organic soils or waste sludges. In this method special mixing tools are used, which are in most cases fixed to an excavator’s rig arm. Mixing is executed vertically or horizontally, with mixing tools that resemble screw propellers incorporating a central nozzle for the binder. The binder is fed from a separate unit which houses the pressurised binder container, compressor, air dryer and supply-control unit. Stabilisation is executed in phases, depending on the operational range of the drilling rig, which generally comprises an area of 8 to 10 m² and a depth up to approx. 4 m. Once the required binder volume has been applied, mixing is continued to ensure the optimum mix properties.
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