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

The Deep Soil Mixing method (DSM), further developed by Keller, was invented in Japan and Scandinavia. Its use is growing across the world in strengthening and sealing weak and permeable ground. The method helps to achieve significant improvement of mechanical and physical properties of the existing soil, which after mixing with cement or compound binders becomes the so-called soil-mix (or soil-cement). The stabilised soil material that is produced generally has a higher strength, lower permeability and lower compressibility than the native soil. Although the DSM technology is based on simple principles it requires, on the one hand, having significant experience and expertise in associated 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 which has to be improved can be mixed mechanically other with a slurry including binder (wet DSM) or with a dry binder (dry DSM). Jetting of slurry can be also used to enhance mechanical mixing.

The wet method is more appropriate in soft clays, silts and fine-grained sands with lower water 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 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 ground to match adopted design requirements, so eliminating problematic excavation and replacement or more expensive deep foundation methods. Wide application range and variable patterns of execution of soil mixing columns allow for obtaining safe and very economic ground engineering solutions. The use of non-toxic binders as soil additives, including industrial by-products, as well as reduced spoil volumes comparing with jet grouting or classical drilled piles, for example, allow to position DSM as an environmentally friendly technology. The execution practice and quality control of DSM works follow 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
- Environmental stabilisation and solidification
### The wet DSM method

**Mechanical wet deep soil mixing**

In Keller’s deep soil mixing method a special mixing tool is inserted into the soil on site. This mixing tool comprises a drilling rod, transverse beams and a drill end with a head. The drilling causes no vibrations, and is assisted by cement slurry outflow from nozzles purposely located at the end of the soil auger. Once the depth specified by the design is reached, the construction phase of DSM columns commences. Basically the diameter of such columns may vary from 40 to 240 cm, depending on application. The mixing tool, which may also move up and down along the column length to improve homogeneity of soil-mix, assures throughout mixing of the slurry with the soil.

The composition and volume of injected slurry is adapted to the required properties of 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. Bending capacity of DSM elements can be increased 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.
**Quality Control**

QC and QA is obtained from the installation records of the columns and from the results of appropriate 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. Specimen 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 be also 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 stabilised soil.

**Design**

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

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**Exposed DSM columns**

**Examples of DSM column patterns**

**Exposed cut-off wall with secant DSM columns**

**Exposed DSM columns for a bridge support**
Contrary to the wet method, dry soil mixing is only possible in soils that have sufficient moisture content to allow chemical reaction of stabilising binders injected in dry form with the soil and groundwater. The basic advantages of dry mixing is that stabilisation effects can be obtained in deep deposits of very weak soils, including organic ones, with high productivity, almost no spoil and cost effective. Also operations at low temperatures are possible.

Typical equipment for dry DSM comprises stationary or mobile binder storage and feeding plant and a purposely 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, with mixing tool rotation direction reversed to the penetration phase direction. 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 feeding 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.
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 having a centrally provided nozzle for 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, according to the operational range of the drilling rig, which generally comprises an area of 8 to 10 m² and depth up to approx. 4 m. Once the required binder volume has been applied, mixing is continued to assure the optimum mixing properties.

Quality Control
Similarly as for DSM columns constructed with the wet method, quality assessments and performance monitoring methods 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, which are feasible in columns designed for lower strength, and include Modified Cone Penetration Tests and Pull Out Resistance Tests to avoid the problem of the cone's tendency to steer out of longer columns. Also laboratory tests on specimens extracted from exposed columns can be carried out, if required.