The Cement Deep Mixing (CDM) method is a technique to chemically solidify and strengthen soft ground by in-situ mixing of the soil with cement slurry.

In recent years this high quality, environment friendly, low cost ground improvement technology has become the most popular ground improvement method.

The CDM method is often superior to other methods in a wide range of ground improvement applications such as prevention of embankment instability and settlement, improving ground stability for construction projects, countermeasures against liquefaction, and reinforcement of ground to improve earthquake-response of superstructures.

The Cement Deep Mixing Association is a consortium of private firms including general contractors, marine works contractors, and foundation works contractors. Its function is to promote and improve the CDM method. The CDM Association has managed to introduce the method for use in numerous successful soil improvement projects throughout Japan; and consequently the use of CDM continues to increase steadily.
Advantages of the CDM method

1. Assures achievement of required strength
2. Shortens the construction period
3. Prevents settling
4. Improves earthquake resistance
5. Does not pollute or contaminate the environment
6. Has wide applicability
7. Enables reliable quality control
8. Uses resources effectively
9. Lowers construction costs
Cement Deep Mixing (CDM) is a method for improving the ground to a prescribed strength by mixing cement slurry with the soft soil in situ. Generally, the cement used is either ordinary portland cement or a mixture of portland cement and blast-furnace slag. The cement alone creates cementitious materials through hydration; and, although the reaction differs with the soil type, the calcium hydroxide liberated from the cement also undergoes a pozzolanic reaction with the soil to create cementitious materials. As the mixture ages, these cementitious materials gradually fill the void space between the soil particles, which results in higher strength and lower volume compressibility of soil.

**CDM Control System**

The CDM machine is equipped with a construction control system, which enables the real-time monitoring and control of execution values and insures reliable treated soil columns.

![CDM Control System Diagram](image)

**Relation between cement ratio and strength (at 4 weeks)**

![Graph showing relation between cement ratio and strength](image)

*\( \alpha \): Weight of cement per unit volume of soil

**\( \text{qu} \): Unconfined compressive strength (in MN/m\(^2\); 1 MN/m\(^2\) = 10 kgf/cm\(^2\))
Design of improved ground

Design procedure varies according to the configuration of the improvements: block type, wall type, grid type, or group column type.

**Design procedure for block type or wall type improvement**

- **Determination of design conditions**
  (Functional and performance requirements)

- **Examination of external stability of superstructures**

- **Specifications of improvement**

- **Examination of external stability of improved ground**
  - Calculation of external forces
  - Sliding
  - Over-turning
  - Reaction force of ground
  - Allowable bearing capacity of original ground

- **Examination of internal stability**
  - Calculation of external forces
  - Toe pressures
  - Shear stress analysis
  - Extrusion failure of untreated soil (for wall type improvement)

- **Slip circle analysis**

- **Examination of displacement**

- **Determination of strength and specifications of the improved ground**

**Detailed design**

**Design procedure for group column type improvement**

- **Determination of design conditions**
  (Functional and performance requirements)

- **Determination of dimensions for superstructure**

- **Specifications of improvement:**
  - Strength
  - Improvement range and depth
  - Arrangement of stabilized columns
  - Improvement area ratio

- **Examination of sliding stability**
  Slip circle analysis
  - through the improved ground
  - outside the improved ground

- **Examination of bearing capacity**

- **Examination of settlement**

- **Determination of strength and specifications of the improved ground**

**Detailed design**

References:
1. Coastal Development Institute of Technology (1999); Technical Manual of Deep Mixing with Respect to Marine Works
3. Coastal Development Institute of Technology (2002); The Deep Mixing Method Principle, Design and Construction
**Application of CDM**

Besides its use in improving foundation ground for many types of structures, CDM can also be used for temporary structures, such as cut-off walls and shoring barriers, and to ensure ground stability during excavation for construction projects.

**Selection of appropriate CDM processes (On-land works)**

- **Design and working condition**
  - Condition of ground to be improved
  - Objectives of improvement
  - Ratio of improvement depth and improvement area
  - Environmental restrictions

- **Distance to the adjacent structures**
  - X / L' ≥ 1.0

- **Depth of improvement**
  - L' ≤ 20m
  - L' > 20m

- **Original soil condition**
  - C ≤ 40 kN/m² (Clayey soil)
  - N (SPT) ≤ 10 (Sandy soil)

- **Selection of appropriate process**
  - CDM-Mega (ϕ1300mm X 2) [L' ≤ 20m]
  - CDM-Land4 (ϕ1000mm to 1200mm X 4) [L' ≤ 25m]
  - CDM-Mega (ϕ1200mm X 2) [L' ≤ 30m]
  - CDM (ϕ1000mm X 2) [L' ≤ 40m]
  - CDM-Column21 (ϕ1500mm to 1600mm X 2) [L' ≤ 50m]
To meet the demands of larger projects, the CDM Association has developed a large-scale CDM process, CDM-Mega. The CDM-Mega process has inherited the various merits and features of the conventional dual-shaft system (1000 mm diameter × 2 columns) but the diameter of the mixing blades is increased to 1200 – 1300 mm. CDM-Mega can reduce the cost of a project in terms of both time and money.

### Specifications of CDM machines

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Component</th>
<th>10 m or less deep</th>
<th>20 m or less deep</th>
<th>30 m or less deep</th>
<th>40 m or less deep</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 mm X 2</td>
<td>Deep mixing machine</td>
<td>45 kW X 2</td>
<td>50 to 60 kW X 2</td>
<td>75 to 90 kW X 2</td>
<td>90 kW X 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leader length: 20 m</td>
<td>Leader length: 30 m</td>
<td>Leader length: 50 m</td>
<td>Leader length: 55 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hoisting: 25 t to 27 t</td>
<td>Hoisting: 35 t to 37 t</td>
<td>Hoisting: 50 t to 55 t</td>
<td>Hoisting: 50 t to 55 t</td>
</tr>
<tr>
<td></td>
<td>Engine power generator</td>
<td>250 kVA</td>
<td>300 kVA</td>
<td>450 kVA</td>
<td>450 kVA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cement slurry plant</td>
<td>10 m³/h</td>
<td>20 m³/h</td>
<td>20 m³/h</td>
<td>20 m³/h</td>
</tr>
<tr>
<td></td>
<td>Backhoe</td>
<td>0.6 m²</td>
<td>0.6 m²</td>
<td>0.6 m²</td>
<td>0.6 m²</td>
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### Specifications of CDM-Mega

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<th>Remarks</th>
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<tr>
<td>1200 mm X 2</td>
<td>Deep mixing machine</td>
<td>75 to 90 kW X 2</td>
<td>90 kW X 2</td>
<td>90 to 110 kW X 2</td>
<td>90 to 110 kW X 2</td>
<td>for mixing motor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leader length: 20 m</td>
<td>Leader length: 30 m</td>
<td>Leader length: 50 m</td>
<td>Leader length: 55 m</td>
<td>for slurry plant</td>
</tr>
<tr>
<td></td>
<td>Engine power generator</td>
<td>450 kVA</td>
<td>600 kVA</td>
<td>600 kVA</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cement slurry plant</td>
<td>40 m³/h</td>
<td>40 m³/h</td>
<td>40 m³/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Backhoe</td>
<td>0.6 m²</td>
<td>0.6 m²</td>
<td>0.6 m²</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Component</th>
<th>10 m or less deep</th>
<th>20 m or less deep</th>
<th>30 m or less deep</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1300 mm X 2</td>
<td>Deep mixing machine</td>
<td>90 kW X 2</td>
<td>90 to 110 kW X 2</td>
<td>90 to 110 kW X 2</td>
<td>for mixing motor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leader length: 20 m</td>
<td>Leader length: 30 m</td>
<td>Leader length: 50 m</td>
<td>Leader length: 55 m</td>
</tr>
<tr>
<td></td>
<td>Engine power generator</td>
<td>600 kVA</td>
<td>600 kVA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cement slurry plant</td>
<td>40 m³/h</td>
<td>40 m³/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Backhoe</td>
<td>0.6 m²</td>
<td>0.6 m²</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Column shapes

<table>
<thead>
<tr>
<th>Cross-section</th>
<th>Example of pile arrangement in group column type</th>
<th>Column type</th>
<th>block type</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1200 mm X 2</td>
<td>![Cross-section diagram](#1200 mm X 2)</td>
<td>2.17 m²/set</td>
<td></td>
</tr>
<tr>
<td>Overlapping: 200 mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#1300 mm X 2</td>
<td>![Cross-section diagram](#1300 mm X 2)</td>
<td>2.56 m²/set</td>
<td></td>
</tr>
<tr>
<td>Overlapping: 200 mm</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CDM-LODIC inflicts minimal impact on the surrounding ground and structures. The conventional CDM has gained wide popularity because it causes less displacement than other ground improvement methods; but CDM-LODIC, which uses auger screws on the upper part of the mixing shaft to discharge a volume of soil equal to the amount of cement slurry that is injected, causes even less displacement. As a result, CDM-LODIC is able to accomplish soil improvement with minimal influence on the surrounding ground and structures.

The CDM-LODIC method may use continuous, intermittent, or propeller type auger screws. Reliability is guaranteed with the use of the execution control system to monitor and regulate the volume of soil extracted.

### Ground Displacement Measurement

The graph compares the horizontal displacement of the surrounding soil 1.5 meters from the deep mixing operation. The influence of the execution is drastically reduced by the application of CDM-LODIC.

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>AP+6.0</th>
<th>Cover soil</th>
<th>AP-1.1</th>
<th>Sandy soil</th>
<th>AP-3.2</th>
<th>Upper clayey soil</th>
<th>AP-17.6</th>
<th>Lower clayey soil</th>
<th>AP-26.9</th>
<th>Sandy soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal displacement (cm)</td>
<td>0</td>
<td>0.44</td>
<td>3.30</td>
<td>16.11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Procedure

1. Positioning the machine
2. Penetration/Soil extraction
3. Mixing at the bottom
4. Retrieval/Slurry injection/Mixing/Soil extraction
5. Completion, to the next column

Soil extracted at step 2 or 4
The CDM-Column21 process can shorten working time by using two rotating shafts with large mixing heads of 1.5 m diameter. The mixing head consists of a 2-stage structure of an upper mixing unit and a lower mixing unit, both of which are equipped with outer and inner mixing blades rotating in opposite directions. This unique counter rotating action of the blades actualises the shearing mixing effect and ensures uniform mixing of the cement slurry with the soil. With its strong driving torque, CDM-Column21 can be applied to harder ground formation or enables treating ground where hard ground is sandwiched between soft layers.

CDM-Land4 uses four shafts operating simultaneously, which greatly increases capacity and reduces construction costs. This four shaft simultaneous operation also increases the mixing efficiency and consequently offers higher-quality soil improvement.

### Specifications of CDM-Column21

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500 mm X 2</td>
<td>Deep mixing machine</td>
<td>75 kW X 2 Leader length: 18 m–33 m Hoisting: 65 t</td>
</tr>
<tr>
<td></td>
<td>Engine power generator</td>
<td>600 kVA (for mixing motor) 300 kVA (for slurry plant)</td>
</tr>
<tr>
<td></td>
<td>Cement slurry plant</td>
<td>60 m³/h</td>
</tr>
<tr>
<td></td>
<td>Backhoe</td>
<td>0.6 m³</td>
</tr>
</tbody>
</table>

### Specifications of CDM-Land4

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Item</th>
<th>10 m or less deep</th>
<th>20 m or less deep</th>
<th>25 m or less deep</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 mm X 4</td>
<td>Deep mixing machine</td>
<td>45 kW X 4 Leader length: 20 m Hoisting: 50 t to 55 t</td>
<td>50 – 60 kW X 4 Leader length: 30 m Hoisting: 60 t to 65 t</td>
<td>75 – 90 kW X 4 Leader length: 36 m Hoisting: 70 t to 75 t</td>
<td>for mixing motor</td>
</tr>
<tr>
<td></td>
<td>Engine power generator</td>
<td>250 kVA X 2 200 kVA</td>
<td>300 kVA X 2 200 kVA</td>
<td>450 kVA X 2 200 kVA</td>
<td>for slurry plant</td>
</tr>
<tr>
<td></td>
<td>Cement slurry plant</td>
<td>40 m³/hr 40 m³/hr</td>
<td>40 m³/hr 40 m³/hr</td>
<td>40 m³/hr 40 m³/hr</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Backhoe</td>
<td>0.6 m³ 0.6 m³</td>
<td>0.6 m³ 0.6 m³</td>
<td>0.6 m³ 0.6 m³</td>
<td></td>
</tr>
<tr>
<td>1200 mm X 4</td>
<td>Deep mixing machine</td>
<td>75 – 90 kW X 4 Leader length: 20 m Hoisting: 50 t to 55 t</td>
<td>90 kW X 4 Leader length: 30 m Hoisting: 80 t to 65 t</td>
<td>90 kW X 4 Leader length: 36 m Hoisting: 70 t to 75 t</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Engine power generator</td>
<td>450 kVA X 2 200 kVA</td>
<td>600 kVA X 2 200 kVA</td>
<td>600 kVA X 2 200 kVA</td>
<td>for mixing motor</td>
</tr>
<tr>
<td></td>
<td>Cement slurry plant</td>
<td>40 m³/hr 40 m³/hr</td>
<td>40 m³/hr 40 m³/hr</td>
<td>40 m³/hr 40 m³/hr</td>
<td>for slurry plant</td>
</tr>
<tr>
<td></td>
<td>Backhoe</td>
<td>0.6 m³ 0.6 m³</td>
<td>0.6 m³ 0.6 m³</td>
<td>0.6 m³ 0.6 m³</td>
<td></td>
</tr>
</tbody>
</table>
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Cement Deep Mixing

Method - in situ mixing of soil with cement slurry - is a patented process.

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