Deep Mixing Method: A Global Perspective

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Abstract

Various types of contemporary Deep Mixing Method (DMM) techniques have been used in the United States since 1986. Such techniques owe their origins to Japanese and Scandinavian developments, which began almost three decades ago. The growing demands of urban infrastructure development and rehabilitation have created a very active and rapidly expanding market demand in the United States especially since the early 1990s, and there is a clear need for a new and fundamental review of the surprisingly large number of DMM techniques that are being used domestically, or are available in other parts of the world. Following a summary tracing the historical development of DMM, and a generic classification of applications, the paper provides a review of each of the many different proprietary methods, which the authors have identified during preparation of an international survey funded by the Federal Highway Administration (FHWA). Data are also provided on commercial aspects of the various DMM techniques worldwide.

Introduction

The Deep Mixing Method (DMM) encompasses a group of technologies that provide in situ soil treatment. Materials of various types, but usually of cementitious nature, are introduced and blended into the soil through hollow, rotated shafts equipped with

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cutting tools, and mixing paddles or augers that extend for various distances above the tub. The materials may be injected in either slurry (wet) or dry form. The treated soil or fill mass that results generally has a higher strength, lower compressibility and (usually) lower permeability than the virgin soil, although the exact properties obtained will reflect both the characteristics of the native soil, and the construction techniques and variables that are selected.

Although the original concept appears to have been developed in the United States in 1954, current practice reflects the intense efforts of researchers, backed by strong federal and state demands in both Japan and Scandinavia since 1967. During the last decade, however, domestic challenges to the specialty ground engineering community in the arenas of urban infrastructure development, seismic mitigation and environmental remediation, have led to a rapid growth in the use of such techniques in the United States also.

Recent international conferences, such as in Toka in 1996 and Logan, UT in 1997, have highlighted that there exist a surprisingly large number of different DMM techniques, each one typically proprietary to one, or a group of, specialty contractors. It is also clear that each technique has its own particular advantages and limitations, technically, logistically, and environmentally.

Given the rapid growth in the usage of DMM in the United States, it is therefore timely to present a global overview of these various different techniques so that they can be better understood by the engineering community and so more appropriately used. This paper first provides a summary of the historical evolution of DMM so that the reader can appreciate the lineage of the respective methods. It continues by briefly summarizing the main groups of applications, and comparing DMM with competitive methods in each category. The main focus of the paper, however, is the tabulation within a new generic classification framework of the different techniques, their characteristics, equipment, performance and so on. The paper concludes with a presentation of some commercial data relating to both domestic and international usage. Space restrictions prevent a more detailed review of treated soil properties, or a discussion of the advantages and disadvantages of DMM relative to alternative or competitive technologies. The interested reader is referred to the FHWA study (1994).

Historical Evolution

Table 1 provides a chronology of the major events in the ongoing development of the DMM techniques. It refers to a large number of these techniques by name, bearing in mind that the details of these techniques themselves are provided in Appendices 1 and 2. Table 1 highlights the commitment and energy of engineers in Scandinavia and Japan for over 30 years, initially pursuing similar paths, but soon following different directions in response to particular national demands. Also apparent is the accelerating rate of progress in other regions, principally the United States and Western Europe, over the last 10 years.

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974</td>
<td>Inyoung Pulp Co. (U.S.) develop Mix-in Place (MIP) Piling Technique (single gauge), and see sporadic use in the U.S., though widespread use continues in Japan till early 1990s.</td>
</tr>
<tr>
<td>1977</td>
<td>Port and Harbor Research Institute (PHRI, Ministry of Transportation, Japan) begin laboratory tests, using granular line for treating soft marine soils (CLM). Research continued by Okumura, Teshi et al. through early 1970s to: a) investigate fine-marine clay reaction and b) develop appropriate mixing equipment (U.S. at 0-1 to 1 MPa achieved). Early equipment used on first trial in 1963 near Nara.</td>
</tr>
<tr>
<td>1978</td>
<td>Laboratory and field research begins in Sweden. Lindehagen method for treating soft ground in submerged embankments using trenching line from Kjel Puls, Lindesö, Alnäs AB, in cooperation with Swedish Geotechnical Institute (SGI), Euro-AB and Byggföretagen AB.</td>
</tr>
<tr>
<td>1974</td>
<td>PHRI report that the Deep Mixing method (DMM) has commenced full scale application in Japan. First applications in reclaimed soft clay at Chiba. DMM continues to be used until late 1970s when CDM and DJM supersede it.</td>
</tr>
<tr>
<td>1975</td>
<td>Following researches from 1973 to 1974, PHRI develop the forerunner of the current Deep Mixing method (CDM) using cement grout and employ it for the first time in large scale projects in soft marine soils offshore. (Original variants include DCM, CMC (still in use from 1974), then DDCM, DECAM, Demin, etc.)</td>
</tr>
<tr>
<td>1976</td>
<td>Public Works Research Institute (PWRI) (Ministry of Construction, Japan) begins research on the DPM Mixing method (DMM) using dry powdered cement (or less commonly, quick-clin), &quot;first practical stage&quot; completed in late 1970s. Representatives of PHRI also participate.</td>
</tr>
<tr>
<td>1976</td>
<td>SMW method used commercially for first time in Japan.</td>
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<tr>
<td>1980</td>
<td>SMW method used commercially for first time in Japan.</td>
</tr>
<tr>
<td>1983</td>
<td>SGI (Sweden) publishes 10 year progress review. (Länsberg and Holm).</td>
</tr>
<tr>
<td>1986</td>
<td>SMW and Seiko Inc. commerce operations in U.S. under license from Seiko Kogyo.</td>
</tr>
</tbody>
</table>

Table 1. Highlights of Historical Development of DMM (continues).
SOIL IMPROVEMENT FOR BIG DIGS

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>1988 - 1999</td>
<td>Development by Geocon, Inc. in U.S. of DSM (Deep Soil Mixing) and SSM (Shallow Soil Mixing) techniques.</td>
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<tr>
<td>1989</td>
<td>Start of exponential growth in use of Lime/Cement Columns in Sweden and Finland.</td>
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<tr>
<td>1992 - 1994</td>
<td>SMW method used for massive earth retention and ground treatment project at Logan Airport, Boston.</td>
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<tr>
<td>1994</td>
<td>First commercial application of original Geojet system in the U.S. (Texas) following several years of development by Brown &amp; Root.</td>
</tr>
<tr>
<td>1995</td>
<td>Swedish Geotechnical Society publishes new design guide for lime and lime-cement columns (P. Cahnsten).</td>
</tr>
<tr>
<td>1995</td>
<td>SGI (Sweden) publishes 21-year experience review.</td>
</tr>
<tr>
<td>1997</td>
<td>Hayward Baker install 1.2 to 1.8 m diameter columns for foundation, earth retention and ground improvement.</td>
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<tr>
<td>1997</td>
<td>SMW method used for huge soil treatment project at Fort Point Channel, Boston, MA (Largest DMM project to date in North America), and other adjacent projects. Input at design stage to U.S. consultants by Dr. Teraishi (Japan).</td>
</tr>
<tr>
<td>1997</td>
<td>First commercial use in U.S. of modified Geojet system (by Condon Johnson Associates at San Francisco Airport, CA).</td>
</tr>
<tr>
<td>1997</td>
<td>Major lime-cement column application (1-11, Salt Lake City) proposed by Swedish contractor, Stabilizer.</td>
</tr>
<tr>
<td>1997</td>
<td>Rafty Kegy (Japan) establishes U.S. subsidiary in California.</td>
</tr>
<tr>
<td>1997 - 1998</td>
<td>Master Builders Technologies develop family of dispersants for soil (and grout) to aid DMM penetration and mixing efficiency.</td>
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</tbody>
</table>

Table 1. Highlights of Historical Development of DMM (concluded).

Application and Applicability of DMM

Six basic groups of applications can be identified for contemporary deep mixing methods:

1. Hydraulic cutoffs: DMM walls to prevent water movement through or under retaining structures, such as canals or levees (e.g., Sacramento, CA) and into deep basements excavated below the water table.
2. Structural walls: DMM walls containing steel elements to resist lateral earth pressures in the construction of deep excavations, such as for cut and cover tunnels (Ted Williams Tunnel, Boston, MA) and deep basements.
3. Ground treatment: Block treatment to strengthen in a uniform manner large volumes of foundation soil in conjunction with deep excavations (Fort Point Channel, Boston, MA), and structural foundations.
4. Ground improvement: Discrete DMM elements (columns or panels); used as reinforcing elements to improve the overall performance of large, compressible soil masses under relatively lightly loaded structures, such as road (e.g., I-15, UT) or railway embankments.
5. Liquefaction mitigation: Interlocking DMM box or cellular structures to reduce the tendency for mass liquefaction and lateral spreading during seismic events under large embankments (e.g., Jackson Lake Dam, WY) or buildings.
6. Hazardous materials: DMM walls to contain, or DMM block treatment to fix, environmentally unacceptable materials.

Classification of Methods

A generic classification of the numerous methods used internationally can be made on the following simple basis:

- Is the cementitious material injected in a slurry or wet (W) form, or in a dry (D) state?
- Is this binder mixed with the soil via rotary energy only (R) or is the mixing enhanced/ facilitated by high pressure jet (J) grout type methods?
- Is the mixing action only occurring near to the drilling tool (E), or is it continued along the shaft (S) for a significant distance above it, via augers and/or paddles?

The classification shown on Figure 1 has therefore been developed by the authors, and four categories of methods - WRS, WRE, WJE, and DRE - have been identified. No methods have been found in the DRR, DJE, or DJS categories since dry injection methods only feature end mixing with relatively low pressure binder injection pressures via compressed air, and jetted methods only feature end mixing (hence no WJS).
Features of Methods:

The FHWA Report (1998) provides extensive data on each of the methods identified in Figure 1. Space restrictions prevent more than a brief summary of the more significant methods being provided in this publication (Appendices 1 and 2). The following general points must be borne in mind while considering these data:

- New methods, refinements of existing methods, and developments in materials (e.g., use of flyash, gypsum and slag in slurry, clay dispersants to aid penetration and improve mixing efficiency) are continually underway.
- As noted by Taki and Bell (1997), the technical goal of any DMM technique is to provide a uniformly treated mixed body, with no discrete lumps of bincor or scil, a uniform moisture content, and a uniform distribution of bincor throughout the mass. The most important requirements for installation are therefore: thorough and uniform mixing of the soil and binder, appropriate water/cement ratio; and appropriate grout injection ratio (e.g., volume of grout: volume of treated soil).
- The table includes methods not conventionally or nationally regarded as DMM, for example, the SMW Method (used only for walls in Japan), while the Scandinavian practitioners do not conventionally address their Lime-Cement Column Method as DMM.
- Despite their generic similarity, there are major and significant regional and procedural variations. For example, unconfined compressive strengths (U.C.S.) of treated soil using WRE, WRS, and WJE are typically higher than 1 MPa, except (e.g., FGC-CDM) where lower strengths are deliberately engineered. For DRE methods in Japan (e.g., DJM) a minimum U.C.S. of 0.5 MPa is obtained, whereas for the comparable DRE Scandinavian method (Lime-Cement Columns), rarely are strengths in excess of 0.15 MPa designed and/or achieved. Furthermore, treated soils in Scandinavia may be considered as providing vertical drainage while similar soils in other countries, by other methods, may be regarded as relatively impermeable.
- Table 2 (Terashi, 1997) summarizes the factors influencing the strength of treated soil. In laboratory testing, there is no way to simulate factors 3 and 4 except for the amount of binder and the curing time. Thus laboratory testing features standardization of these factors, and so it must be realized that the strength data provided by such tests is "not a precise prediction" (Terashi, 1997) but only an "index" of the actual strength. Field testing is essential, and invariably appears to provide, for a number of reasons, inferior and more variable strength data.
- Deep mixing is, of course, not a panacea for all soil ground treatment, improvement, retention and containment problems, and in different applications it can be more or less practical, economic or preferable than competitive technologies. In the most general terms, DMM may be most attractive in projects where the ground is neither very stiff nor very dense, nor contains boxters or other obstructions; to depths less than about 30m;
where there is relatively unrestricted overhead clearance; where a constant and good supply of binder can be assured; where a significant amount of soil can be tolerated; where a relatively vibration-free technology is required; where treated or improved ground volumes are large; where "performance specifications" are acceptable; or where treated ground strengths have to be closely engineered (typically 0.1 to 0.3 MPa). Otherwise, and depending always on local conditions, it may prove more appropriate to use jet grouting, diaphragm walling, sheet piling, caissons, beams and legging, driven piles, vick drains, vibrocretes, vibroflotation, compaction grouting, deep dynamic consolidation, bioremediation, or vapor extraction.

The materials injected are tailored to the method used, their local availability, the ground to be treated and the desired or intended result. Generally, for the methods using a fluid grout, the constituents include cements, water, bentonite, clay, gypsum, fly ash, and various additives. Water cement ratios typically range from less than 1 to over 2, although the actual in place w/c ratio will depend on any "predrilling" activities with water, or other fluids. Most recently, dispersants (Gause, 1997) can be used, both to breakdown cohesive soils, and also to render more efficient the grout injected. For dry injection methods, cement and/or unslaked lime are the primary materials used.

For wet methods (mechanically simpler and so preferable in "difficult" geographic locations), the cement injected is typically in the range of 0.1 to 0.5 kg per cubic meter of soil to be treated. The ratio of volume of fluid grout injected to soil mass treated is typically about 20 to 40% (a lower injection ratio is preferable, to minimize cement usage and spoil).

For dry methods, (in soils of 60 to over 200% moisture content), typically 100 to 300 kg of dry materials per cubic meter of treated soil are used, providing strengths of 0.2 to 2 MPa, depending very much on soil type (low strengths and solids contents in Scandinavia), with minimal spoil or heave potential.

Treated soil properties (noting that cohesive soils require more cement to give equivalent strengths than cohesionless soils) are usually in the ranges shown in Table 3.

It must be remembered that different techniques are intended specifically to provide higher strengths, or lower permeabilities and so the figures cited above are gross ranges only, and that the data provided by the individual corporations supersede those presented above for specific applications.

| Table 2. Factors affecting the strength increase (Terashi, 1997). |
|-----------------|-----------------|
| U.C.S. | 0.2 - 50 MPa (0.5 - 5 MPa in granular soils) |
| k    | $10^{-4} - 10^{-4}$ m/s (lower if bentonite is used) |
| E    | 350 to 1000 times U.C.S. for lab samples and 150 to 500 times U.C.S. for field samples |
| Shear strength (direct shear, no normal stress) | 40 to 50% of U.C.S., at U.C.S. values < 1 MPa, but this ratio decreases gradually as U.C.S. increases. |
| Tensile strength | Typically 8 - 14% U.C.S. |
| 28-day U.C.S. | 1.4 to 1.5 times the 7-day strength for silts and clays 2 times the 7-day strength for sands |
| 60-day U.C.S. | 1.5 times the 28-day U.C.S., while the ratio of 15 years to 60 days U.C.S. may be as high as 3 to 1. In general, grous with high w/c ratios have much less long term strength gain than 28 days, however. |

Table 3. Typical data on soil treated by deep mixing.
Commercial Aspects

In the United States, there are at least nine companies who offer or claim to offer deep mixing services. Four (GeoCon, Condon Johnson, Terra, and Millgard) appear to have no links with foreign ownership or licensees, having developed their own systems. The others (Hayward Baker, Rado, Seiko, Stabilator, and SCC) are either U.S. operations with foreign ownership or use methods under foreign license. Based on the authors' investigations, it would seem that from 1986 to 1992, the annual value of deep mixing work conducted was in the range of $10 to 20 million, increasing by over 50 percent to $32. Since then, as a result of massive works in Boston, Salt Lake City and the West Coast, this annual volume is probably now in the range of $50 to 80 million. For DMM used in environmental applications, the annual market may be around $20 to 50 million, increasing at about 5 to 10 percent annually.

Large scale systems may cost $80,000 to $200,000 to mobilize (much lower for methods such as Lime-Cement Columns). Typical prices for treatment are $100 to 250/m³, or $50 to 100/m³.

In Japan, the CDM Association claims to have treated over 26 million m³ of soil from 1977 to 1995 (10 percent in the period 1992 to 1993) with about 60 percent being offshore (Figure 2). The DMM Association records 16 million m³ of soil treatment from 1980 to 1996, involving 2345 separate projects, and an annual volume now approaching 2 million m³ (Figure 3). By 1994, SMV Seiko, referring to their deep mixing wall system, had recorded 4,900 projects worldwide for a total treatment of 125 million m³ (7 million m³).

In Scandinavia, Ahlberg's data (Figure 4) illustrate the rapid growth in Swedish applications, while similar data illustrate a strong but smaller and steadier market in Finland (about 250,000 m³/year, 80 percent of which is lime-cement columns). Markets in Norway and the Baltic countries are much smaller but have considerable growth potential. Selling prices in Scandinavia are typically in the range of 57 to 127/lia.

Similar data have not been found for other European countries, but there is no evidence that levels of activity in countries like U.K., France, Germany and Italy currently approach those in the U.S.
Figure 4. Use of different stabilizing agents for deep stabilization of soils in Sweden 1975-1994 (Ahlgren, 1996).

**Final Remarks**

Deep mixing is one of the world's most attractive and fastest growing specialty geotechnical construction processes. It offers solutions in a wide range of applications, in softer soils to moderate depths. Levels of knowledge and expertise are exceptionally high in Scandinavia and Japan, and rapidly improving in North America, where its technical and commercial potential is now becoming fully recognized. It is hoped that this paper will provide a structured introduction to the many techniques and systems that currently exist and a basis for understanding the innovations that will doubtless follow in quick order.

**Acknowledgments**

The authors have been singularly fortunate to have received input from specialists and colleagues throughout the world from a variety of institutions and corporations. These individuals include Peter Nicholson, Dan Himick, Osamu Taki, Dave Drass, Tom O'Rourke, George Burke, Masaki Tanish, James Johnson, Goran Holm, Johan Hagstrom, David Yang, and Seth Pearlman. To all, our thanks.
References


### Classification
- **Name**: WRS
- **Company**: DSM
- **Geography**: GeCoa
- **Region**: N. America

### General Description of Method
- **Description**: Adjacent discontinuous augers rotate in alternate directions. Most of grout injected mainly on downstream.

### Special Features/Innovated Aspects
- **Lower 1m usually double-stroked.**
- **Stroking**: QA/QC by electronic methods.

### Details of Installation
<table>
<thead>
<tr>
<th>Shells</th>
<th>Diameter (m)</th>
<th>Depth (m)</th>
<th>RPM</th>
<th>Productivity (m³/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4, usually 4</td>
<td>0.6-1.0m usually 0.8m</td>
<td>25m</td>
<td>20-50</td>
<td>2 m³/min penetration</td>
</tr>
<tr>
<td>1-5, usually 3</td>
<td>0.5-1.5m, usually 1m</td>
<td>60m claimed, 35m practical</td>
<td>15-20</td>
<td>0.5-1.0 m³/min penetration</td>
</tr>
</tbody>
</table>

### Mix Design
- **Cement, ground cement and other additives.**

### Reported Treated Soil Properties
- **UCS**: 0.3-3.7 MPa (clay strengths approx. 40% those in sand)
- **k**: 1 x 10⁻⁶ - 1 x 10⁻⁵ m/s
- **E**: 50 to 150 x U.C.S.

### Specific Relative Advantages and Disadvantages
- **Advantages**: Economic, proven systems. Mixing efficiency can be poor iftiff clays. Can generate large spill volumes.
- **Disadvantages**: Developed in 1980s.

### Representative References
- Ryan and Jaspepu (1984, 1992)
- Dev and Ryan (1992)
- Yang (1997)

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### Classification
- **Name**: Trevirix (Multilc)
- **Company**: Trevirini, Sudo
- **Geography**: Italy

### General Description of Method
- **Description**: Adjacent agers rotate in opposite directions. Great injected during penetration. Prestrucked with water is classes. Auger rotation reversed during withdrawal. Mixing occurs over 8-10m length of shaft.

### Special Features/Innovated Aspects
- **Pre-drilling with water additives in very resistant soils.**
- **Process is patented by Trevirisani.**

### Details of Installation
<table>
<thead>
<tr>
<th>Shafts</th>
<th>Diameter</th>
<th>Depth</th>
<th>RPM</th>
<th>Productivity (m³/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-3, typically 3</td>
<td>550-850mm at 450-600mm spacings</td>
<td>25m</td>
<td>15-30</td>
<td>0.25-0.5 m³/min</td>
</tr>
</tbody>
</table>

### Mix Design
- **Materials**: Cement, water mainly used inclusions. Admixtures common.

### Reported Treated Soil Properties
- **UCS**: 0.5-5 MPa (sand), 0.2-1 MPa (clay, silts)
- **k**: < 1 x 10⁻⁶ m/s

### Specific Relative Advantages and Disadvantages
- **Advantages**: Goal is to minimize soil removal (10-20%) and enhance mixing efficiency. Vast amount of B.C.E. information available. Specifically developed for softer marine deposits and fills.

### Representative References
- Pagliaci and Fagotto (1994)
Appendix 1. Details of major fully operational deep mixing techniques (continues).
<table>
<thead>
<tr>
<th>Classification</th>
<th>DRE</th>
<th>DRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Dry Jet Mixing</td>
<td>Lime-Cement Columns</td>
</tr>
<tr>
<td>Company</td>
<td>DJM Association (54 companies)</td>
<td>Various (Scandinavia and Far East); Stabaster (U.S.A.)</td>
</tr>
<tr>
<td>Geography</td>
<td>Japan</td>
<td>Scandinavia, Far East, U.S.A.</td>
</tr>
</tbody>
</table>

**General Description of Method**
- Soil is penetrated while injecting compressed air from the lower blades. Dry materials are injected during withdrawal via compressed air, and reverse rotation.
- Soil is penetrated while injecting compressed air below mixing tool. Dry materials are injected during withdrawal via compressed air, and reverse rotation.

**Special Features/Patented Aspects**
- System patented and protected by DJM Association. Two basic patents (blade design and control system).
- Very low spoil. High productivity. Efficient mixing. Patents are held by the contractors. Strong reliance on computer control.

**Details of Installation**
- Shifts: 1-2 shafts spaced at 0.8 to 1.5m, each with 2 pairs of blades
- Diameter: 1m
- Depth: 33m max
- RPM: 5-50 typically
- Productivity: 50-55 mins for 3m column
- 3-5 m/min withdrawal
- Single shaft, various types of cutting/mixing blades.
- 500-2000mm, typically 600, 800mm
- 25m max
- 150-200, usually 130-170
- 0.6-4.5 m³/min (withdrawal)
- 400-000 ft³/m³/shift

**Mix Design (depends on soil type and strength requirements)**
- Usually cement, but quicklime in days of very high moisture content
- Cement ratio (R = m³/m³)
- 100-200 kg/m³ Range is 100-500 kg/m³ but typical is 106-300 kg/m³
- Cement and lime in various percentages (typically 50:50 or 75:25)
- 21-22 kg/m (600mm diameter); 47 kg/m (800mm diameter)
- i.e., 1-7% of soil

**Reported Treated Soil Properties**
- U.C.S.: Creatly varies depending on soil and binder, 1-10 MPa
- Varies but typically 3.2-0.3 MPa (0.2-0.3 MPa, possible)

**Specific Relative Advantages and Disadvantages**
- Very little spoil; efficient mixing.
- Great deal of R&D experience.
- Smeared for DJM. Excellent Swedish/Finnish research continues.

**Notes**
- Offered in the U.S. by Eaise.
- Developed by Swedish industry and Government, with first commercial applications in mid 1970s.

**Representative References**
- DJM Brochure (1995); Fujita (1996)
- Halm (1994); Rathneyer (1996)

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**Appendix 1. Details of major fully operational deep mixing techniques (concluded).**

**DSM system (Courtesy: GeoCon, Inc.)**

**Appendix 2. Illustrations of various deep mixing methods described in Appendix 1 (continues)**
Schematic of SMW system (Tak and Bell, 1997).

Comparisons of SMW and CDM shaft arrangements (Yang, 1997).

Appendix 2. Illustrations of various deep mixing methods described in Appendix 1 (continue).
Appendix 2. Illustrations of various deep mixing methods described in Appendix 1 (continues).

GeoJet system (Courtesy: Condon Johnson Associates).

Appendix 2. Illustrations of various deep mixing methods described in Appendix 1 (continues).
Details of DJM system (DJM Association, 1994).

Details of mixing tools for Lime-Cement Columns (Courtesy: Stabilator).

Appendix 2. Illustrations of various deep mixing methods described in Appendix 1 (concluded).