Raito provides the geometric and material design for all DSM (Deep Soil Mixing) projects. The geometric design includes the layout design of soil-cement elements or panels to meet the intent of the geotechnical design and to provide a guide for the field installation by using Raito’s DSM equipment. The material design includes the selection and testing of the grout or slurry and soil-grout or soil-slurry mixtures to facilitate wall installation and to obtain the required engineering properties of the DSM walls. Drilling depth, penetration/withdrawal speed, shaft rotation and slurry injection rate were monitored on a real-time basis for accurate mixing control and a uniformly mixed product. As for all Raito’s DSM work, multiple-shaft soil mixing equipment was used for wall installation on the following five projects as summarized. The total contract value and final sum at project completion together with other project information are presented in the table entitled, "Representative Projects by Raito, Inc."

PORT OF OAKLAND PROJECTS
Port of Oakland, with the recommendations of its consultants, Geomatrix Consultants, Inc., CH2M Hill, and Subsurface Consultants, Inc., is the first organization in the United States to use the type of deep mixing equipment developed by the Port and Airport Research Institute of Japan. In contrast to the type of deep soil mixing method developed by Seiko Kogyo for the construction of temporary excavation support/cutoff wall, this method uses a paddle-type bottom mixing tool and a real-time QA/QC monitor system for the production of soil-cement structures for long-term use. The term CDSM (Cement Deep Soil Mixing) was created by Port of Oakland to specify its three deep soil-mixing projects at Port of Oakland and Oakland Airport.

Berths 55/56 and 57/58 Projects, Port of Oakland, California - These projects involved the widening of the existing Inner Harbor Channel and the construction of a container wharf above a new 65-foot deep shoreline cut slope to accommodate large container ships. The container terminal at Berths 55/56 and Berths 57/58 includes 4,800 feet of new wharf structure. CDSM was the method specified for improving loose sandy fill and soft Bay Mud deposits at the site to form the CDSM grid walls along the shoreline to maintain the stability of the cut slope and to limit lateral deformations under earthquake loading conditions. The grid is also expected to limit strain and to mitigate the loss of soil strength due to liquefaction for the unimproved soils within the CDSM cells.

The generalized subsurface conditions encountered along the site of the wharf structure consist of fill; recent bay sediments/channel infill deposits, including normally consolidated Young Bay Mud; Merritt/Posey Sand; and overconsolidated Old Bay Mud. The soft Bay Mud and loose to medium dense clayey sand deposits were encountered below the fill and extended to about 30 to 40 feet along most of the site. However, near the west end of the wharf at Berth 57, a deep channel filled with sediments was encountered extending to depths of up to 87 feet. Groundwater levels vary with tidal fluctuations and are generally between 4 to 10 feet below ground surface.
Oakland Airport Roadway Project, Oakland, California – The construction of Oakland Airport Roadway for the airport expansion required the stabilization of subsurface soils for the construction of three grade separation structures. Loose sandy fills and soft Bay Mud were improved by CDSM for the construction of soil-cement foundations under the MSE wall of the roadway overcrossing, and for the installation of soil-cement gravity retaining walls of the roadway undercrossing. In both cases, multiple rows of the soil-cement wall were used to form a soil-cement block to provide a stable foundation/retaining structure under static loading conditions and limit the lateral deformations under earthquake loading. CDSM was also used to construct two cutoff walls for groundwater control. The CDSM work consisted of soil-cement walls or soil-cement-bentonite walls constructed by in situ soil mixing. Individual soil-cement-bentonite CDSM cutoff walls were used to provide permanent seepage control.

The airport site is located on former tidelands or shallow water areas reclaimed from the bay by adding fill. The generalized subsurface conditions consisted of artificial fill, Young Bay Mud and the San Antonio Formation. The ground water levels generally vary from depths of about 5 to 10 feet below the existing ground surface.

The soil-cement grid walls, soil-cement walls, and soil-cement-bentonite walls were installed using two sets of multiple-axis soil mixing equipment as shown in the picture taken at the Port of Oakland. The in situ soil mixing parameters, including mixing energy and grout ratio, were selected based on the results of laboratory trial mix study. A computer based QA/QC system was used to monitor the wall installation on a real-time basis. Approximately 36,000 cubic yards of grid walls were installed for the Berths 55/56 in 1999 and 64,000 cubic yards in 2001 for Berths 57/58 projects. About 68,000 cubic yards of soil-cement walls and soil-cement-bentonite cutoff walls were installed from April 2001 to January 2002 at Oakland Airport. The design average 28-day unconfined compressive strength of soil-cement was 150 psi for these three projects. The strength testing data of all specimens tested ranged from 2.95 to 3.35 times the design average value for the Oakland Airport and Berths 57/58 projects, respectively. The soil-cement-bentonite cutoff wall for the Oakland Airport Project is required to have a maximum permeability of $1 \times 10^{-6}$ cm/sec. The permeability testing data ranged from $8.8 \times 10^{-7}$ cm/sec to $9.5 \times 10^{-8}$ cm/sec. A view of the exposed soil-cement wall at Port of Oakland is shown in the picture.
TRINIDAD LNG FACILITIES, TRAINS 2 & 3 PROJECT AND TRAIN 4 PROJECT

Raito, in conjunction with its consultants, provided the design and build service to Bechtel on DSM work for these two projects. Raito also provided the material and layout design for the wall construction. The CDSM (Cement Deep Soil Mixing) method was used to construct a grid pattern of soil-cement walls under two 820-foot by 490-foot industrial facilities for Trains 2 & 3 with an average of 9 technical personnel on staff as well as 13 during the peak period and one 1050-foot by 630-foot for Train 4 with an average of 14 technical personnel on staff as well as 21 during the peak period. The grids were created to minimize the generation of excessive pore water pressure during and after earthquakes and to prevent the liquefaction of soils within the foundation area. The soil-cement grids were designed to provide bearing capacity and settlement control by transferring the loads from the mat foundations to the besting stratum at about 40 feet below the ground surface. Each soil-cement grid was 13.8 feet by 17.7 feet and was installed with 3.3 feet embedment in the very stiff to hard clay.

Soil conditions encountered on the project consisted of reclaimed hydraulic fill that resulted in a heterogeneous mixture of loose, silty sands, soft silt, clay and gravel. Underlying the hydraulic fill was the top of the natural younger marine sediment layer, consisting of primarily loose to medium dense silty sand and sand. Below the younger marine sediment layer was the older marine sediment, consisting of medium stiff to hard clay. Ground water was encountered at three to six feet below the ground surface.

A CDSM test section was performed prior to full production to verify that the CDSM equipment, procedures, and mix design could produce the required soil improvement. Load tests were also performed during the test section to determine the amount of settlement when loads were applied to soil-cement columns. Results from the test section demonstrated that the CDSM walls would provide a soil-cement grid of adequate strength, satisfying the geometric, strength and uniformity requirements.

Approximately 200,000 cubic yards of CDSM soil improvement was constructed for Trains 2 & 3 from November 1999 to October 2000. Approximately 250,000 cubic yards of CDSM soil improvement was constructed for Train 4 from June 2002 to August 2003. Triple-shaft CDSM equipment was used for these two projects. Drilling depth, penetration/withdrawal speed, shaft rotation and grout injection rates were monitored in real-time and recorded in 3-foot depth increments to assure accurate mixing control and a uniformly mixed soil-cement product.

The design average unconfined compressive strength of soil-cement was 100 psi at the 28-day curing age and was 130 psi at the 90-day curing age for Train 4. The average strength testing data of approximately 1,000 specimens was about 2 times the design average value. A picture of the exposed soil-cement grid is shown.
DELAYED COKER UNIT PROJECT, ST. CROIX, US VIRGIN ISLANDS
The project consisted mainly of a delayed coker unit, including coker handling and storage facilities. The main delayed coker unit spreads over an area of 336 feet by 204 feet. The major components of the partly underground unit are coker structures extending 330 feet high, a 26-foot deep coke pit, a 36-foot deep settling basin and a coke pad at grade. Surrounding the coke pit, pad, and settling basin is a 13-foot high concrete wall and a series of heavy concrete columns supporting a 125-foot long bridge crane. Raito provided the deep soil mixing construction service to Bechtel as a sub contractor.

The subsurface materials consist of three main strata: hydraulic fill, marine deposits, and limestone. The 10 to 13 feet of fill has a 3 to 7-foot thick layer of desiccated stiff to hard silts and clays with sand, underlain by lenses of soft to medium stiff silts and clays. The hydraulic fill is underlain by the original Bay deposits, which extend down to the weathered limestone unit at depths varying from 55 to 78 feet. While variable from place to place, the marine deposits appear to consist of two continuous layers of silty to clayey sands intercalated with two layers of silty clay. The two sand layers have a standard penetration blow count, N, varying from 3 to 8 and fine contents ranging between less than 5 to 40 percent. These two sand layers had less than 0.4 factors of safety against liquefaction. Beneath the marine deposits is a layer of highly weathered clayey limestone, which becomes less weathered and stronger with depth. The groundwater table is encountered at 15 feet below the ground surface.

The soil-cement foundation and gravity retaining wall were designed by Bechtel Corporation. The coker structure includes two coker drum structures, each weighing 16,500 tons, and a 403-foot high upper steel frame structure. The coker structures’ massive size, weight, and mass distribution coupled with the extreme site-specific conditions of high seismic potential and hurricane force winds result in some of the most severe foundation loads in the Petroleum and Chemical Industry. A cursory assessment of the subsurface soils conditions at the site concluded that the nature and engineering properties of both the fill and marine deposits were not adequate to directly support the heavy loading imposed by the structures. Also, difficulties were anticipated in providing temporary support of excavation and control of water seepage with a 36-foot head. The CDSM soil-cement improvement was utilized for supporting excavation and structural loads.

The CDSM solution was unique in that it provided support to the deep excavation without the use of reinforcement, sheet piling or anchors; it provided support to the heavy structural loads eliminating the need for piling; it provided stability against liquefaction; and it eliminated the need for a de-watering system for the excavation. Overlapped soil-cement columns were used to create a continuous cellular system under the structures and along the perimeter of the excavation. Soil-cement panels were extended to bear on the layer of stiff clay or weathered limestone under the site. The cells have various plan dimensions to provide different replacement ratios to satisfy different load demands. Areas under the coke drum structures, the retaining walls around the perimeter and the deeper settling basin required a 90 percent replacement ratio. Less severely loaded zones under the coke tank and coke pad required only 63 percent and 39 percent replacement, respectively. A cross section along the deepest excavation and the forces were considered in the stability analysis. The design required for an average 90-day unconfined compressive strength of 125 psi. The required static shear strength was taken as one half of the
unconfined compressive strength. The dynamic shear strength used was 130 percent times the value of the static strength. The elastic modulus was taken as 300 times the unconfined compressive strength.

Triple-axis soil mixing equipment was used to install soil-cement grids and gravity walls according to the layout design. The construction began in April 2001 and was completed in October 2001. A total of 70,000 cubic yards of soil-cement was produced with 4 technical personnel on the job. A view of the CDSM gravity wall is pictured.