California Department of Transportation
Doyle Drive Test Program
Contract No. 04A3362

Deep Soil Mixing (DSM) /Cutter Soil Mixing (CSM) Testing Report

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By

Malcolm Drilling Company, Inc.

3524 Breakwater Ave., Suite 108

Hayward, CA 94545

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1. Introduction

Malcolm Drilling (MDCI) was awarded contract 4A3662 to investigate the use of cement deep soil mixing (CDSM) in Colma Sand with potential artesian conditions.

a. Site Subsurface Conditions

Original grade of the site was approximately +10.0'. The site was directly above fourteen feet of fill material and Young Bay Mud. A pressurized aquifer was located from approximately elevations of -4.0' to -25.0'. (The groundwater at the medium dense sand was expected to be under artesian pressure generating a static piezometric level of about 2 ft and possibly more above the existing site grade). Beneath the aquifer is the Colma formation to an elevation of -50.0'. See **Attachment #1, Caltrans Drawings**, for a detailed view of the subsurface conditions.

b. Test Program Objectives

The three objectives of the program were to

i. Determine the best soil/cement ratio for the site
ii. Determine the amount of spoils generated from the operation
iii. Determine the behavior of drilled hole in Colma Sand formation in artesian conditions

2. Test Program Scope

Construct two 10' by 10' blocks on a plan area using Deep Soil Mixing (DSM) Method and Cutter Soil Mixing (CSM) methods. Additionally the CSM technique would be utilized to create a 10' by 10' cell on a plan area. The DSM block and the cell would be mixed two feet into the Colma Sand, at elevation -27'. The CSM block would be mixed to the approximate elevation of Stiff Old Bay Mud, at elevation -50'.

Following the completion and cure of the CDSM columns construct a 5 ft diameter test CIDH pile in each of the CDSM columns to a specified pile tip elevations of -45.0 ft.

3. Installation and Equipment Methods

a. Cutter Soil Mixing (CSM)

i. The cutter head of the CSM system is driven into the ground at a continuous rate. The soil matrix is broken up by the cutting wheels and at the same time a fluid is pumped through a set of nozzles, located between the cutting wheels, where it is mixed thoroughly with the loosened soil. The direction of rotation of the wheels can be changed at any time. The direction of rotation used on this project was from the outside inwards. The rotating wheels and cutting teeth push the soil particles through vertically mounted shear plates that have the effect of a compulsory mixer. Penetration speed of the cutter and the volume of fluid pumped into the soil are adjusted by the operator to optimize the absorption of power and to create a homogeneous, fluid, mass that permits easy penetration. Spoils were placed into a designated spoils area and then transported to an approved disposal location. More information is available in **Attachment #2, CSM Tech Submittal**.

b. Deep Soil Mixing (DSM)

   i. The mixing tool was driven into the ground at a rate equal to the required injection volume of cement grout. The soil matrix was broken up by the soil mixing tool and at the same time a fluid is pumped through a set of nozzles, located below the mixing blades, where it was mixed thoroughly with the loosened soil as the blades progressed. Penetration speed of the soil mixing tool and the volume of fluid pumped into the soil are adjusted by the operator to optimize the absorption of power and to create a homogeneous, fluid, mass that permits easy penetration and extraction of the machine. Spoils were placed into a designated spoils area and then transported to an approved disposal location. More information is available in **Attachment #3 DSM Tech Submittal**.

c. Mixing Plant

   i. The grout plant used was an Obermann MP1000. Photos of the mixing plant and silos setup are below.

4. Mix Design for CSM and DSM

a.

Cement	550 kg (1210 pounds)
Water	500 liters (132 gallons)
Bentonite	55 kg (121 pounds)
W/C ratio	0.909
Injection rate	(50% Vol. Column)
Specific gravity of grout	1.58 +/- 0.2

b. The injection rate used during construction was 50%. This created a cement content of 262 kilograms of cement per cubic meter of treated soil.

5. CSM and DSM Test Program, Construction Sequence and Observations

a. The sequence of installations of the piles is included in **Attachment #8 Sequence of DSM and CSM.**

b. The total amount of spoils for the jobsite was **350 CY.**
   i. Large Diameter DSM (37Ft) – 130 CY (37% of total spoils)
   ii. CSM (37Ft) – 67 CY (19% of total spoils)
   iii. CSM (60Ft) – 153 CY (44% of total spoils)

6. Installation of Cast-in-Drilled Hole Piles (CIDH)

a. Pile construction began on January 21, 2010. Pile No. 01 was placed in the center of four mixed DSM piles. This block of soil cement extended to a depth of 37 feet below grade, while the CIDH pile was planned for a depth of 55 feet below grade. MDCI drilled to a depth of 35 feet in the dry. At 35 feet MDCI charged the hole with water and polymer to 5 feet from the top of grade. MDCI continued drilling to a depth of 56 feet with a digging bucket.

As MDCI advanced the hole water and polymer were added. After reaching design depth, and while waiting for the suspended materials to settle out for final cleaning, 4 feet of hole was lost due to loose material falling into the drilled hole. MDCI added more polymers (total of eleven 7.5 lb jugs of polymer and one 5 gal drum of stablelight) and removed one more bucket. The hole was then re-measured and an additional 10 feet of hole was lost due to new material falling in the hole. *MDCI's assumption is that the unconditioned native soil between the drilled shaft and the CSM panel in Block #2, from approx. Elev -27'-0 to Elev -45'-0, sloughed off and continued to fill the bottom of the CIDH shaft despite polymers being added*.

Caltrans was contacted and MDCI was directed to place lean concrete in the hole and re-drill the following day. MDCI placed 54 yards of 2 sack cement, 2 sack flyash, which brought the hole to a depth of 25.5 feet below grade.

b. On January 22, 2010 MDCI returned to the lean concrete hole that was placed the day before. MDCI proceeded to re-drill the hole to 56 feet below grade. One hour after cleaning out the hole the cage was set at approximately 55 feet below grade and while waiting for concrete to be delivered, 2.5 feet of hole was lost again. MDCI then pulled the cage out and cancelled concrete delivery. Kathy Karroubi (Caltrans) contacted Tyler Darland (Caltrans), and Mr. Darland directed MDCI to abandon the hole. MDCI poured 22 CY of lean mix into hole to a depth of 33 feet below grade.

c. On January 25, 2010, MDCI began drilling CIDH pile No. 02. This pile was placed in the center of the 10' by 10' block of CSM mixed soil. (Note, this soil was mixed to a depth of 60 feet below grade; 5 feet below the tip of the proposed CIDH pile). Pile No. 02 was drilled to a depth of 55 feet and the cage was set and poured without issues. The entire hole was completed in the dry and Caltrans directed MDCI to remove inspection tubes from the cage

before it was placed.

7. Coring of Selected DSM and CSM Panels

a. Five cores were planned for the site. Coring was performed by Gularte & Associates, Inc. from 1/26/10 to 1/28/10 and 2/3/10 to 2/5/10. Gularte & Associates used a PQ3 system with a 3.5" I.D. Core. Locations of these cores are included in **Attachment #4 Coring Locations**. The core logs from Gularte & Associates are included as **Attachment #5**. Photos from Gularte & Associates are Included as **Attachment #6**.

b. Strength Results

Table 1: Unconfined Compressive Strength of Cores

Approximate Depth	Core #1	Core #2	Core #3	Core #4
	14 Day Break	28 Day Break	28 Day Break	46 Day Break
	CSM1B	DSM 3	CSM1A	CSM3C
(ft)	(psi)	(psi)	(psi)	(psi)
5	236	254	533	480
10	455	388	229	710
15	446	217	729	530
20	502	297	715	660
25	689	515	624	1000
30	588	584	501	970,660,900,510
35	555	222	326	620
40	582	316	442	
45	240		240	350,600
50	265		265	530
55	343		343	840
60	403		403	450

8. Testing Results

a. Grab samples were taken from each column and tested for unconfined compressive strength. The results of these tests are included as **Attachment #9**.

b. Grab samples of selected cores also were tested for permeability. A summary of the results is provided in Table #2, Hydraulic Conductivity. The detailed reports are included as **Attachment #7**

Table 2: Hydraulic Conductivity

	Hydraulic Conductivity		
	Sample 1	Sample 2	Average
	(cm/s)	(cm/s)	(cm/s)
TestPile	1.00E-07	1.00E-07	1.00E-07
TP4	3.00E-07	2.00E-07	2.50E-07
CSM3A	4.00E-08	3.00E-08	3.50E-08
CSM4C	2.00E-08	4.00E-08	3.00E-08

Attachments

1. Caltrans Drawings
2. CSM Tech Submittal
3. DSM Tech Submittal
4. Coring Locations
5. Core Logs
6. Core Photos
7. Permeability Results
8. Sequence of DSM and CSM
9. Unconfined Compressive Strength
10. Drill Rig Production Logs