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Design and Construction of a Soil Bentonite Slurry Wall around an Operating Facility Superfund Site

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SYNOPSIS: A soil bentonite slurry wall was designed for an NPL site to stop further migration of chemicals in a complex aquifer system, and to facilitate the removal of possible chemical sources from saturated zones beneath the site. Pumping from within the slurry wall will maintain inward and upward hydraulic gradients and thus stop further lateral or vertical migration of chemicals from the contained area. The slurry wall was constructed under an exceptionally detailed Quality Assurance/ Quality Control review by the Contractor and two independent consulting firms. Ground movements, vibration levels and opacity of dust produced during construction were monitored for compliance with design specifications. It was made a condition of the contract that no hazardous material could leave the site. Federal regulations required all persons involved in site work to have health and safety training. Careful planning and close liaison between the Owner, Engineer and Contractor has enabled the slurry wall to be constructed in a business park environment around an operating manufacturing facility without disruption to production.

INTRODUCTION

A soil bentonite slurry wall was constructed around the perimeter of a facility belonging to the Raytheon Company Semiconductor Division (Ellis Street site), Mountain View, California (Owner) between June and October, 1987. Although a large number of soil bentonite slurry walls have been installed in the past for dam cut-offs and deep open excavations, this soil bentonite wall was unique in that the wall was constructed in a business park environment around an operating facility. This setting required considerable foresight in the preparation of contract documents and in coordination between the Contractor and the Owner in order to avoid delays to either party during construction of the slurry wall. Pumping from within the slurry wall will maintain inward and upward hydraulic gradients and thus stop any further vertical or lateral migration of chemicals from the contained area. Wall construction was accompanied by an exceptionally detailed Quality Assurance/ Quality Control (QA/QC) review performed by the Contractor and two consulting firms.

SITE DESCRIPTION

The site is situated in Mountain View, California, ("Silicon Valley"), between San Francisco and San Jose, and was placed on the National Priorities List (NPL), owing to the presence of chemicals in the ground and ground water. The site is at approximately fifty feet above sea level, with a drop in grade of approximately nine feet between the south west and north east corners. The site measures approximately 1000 feet by 840 feet, and is shown on Figure 1.

The Ellis Street facility is a one story building where semiconductor products are manufactured. The building contains equipment sensitive to vibrations and dust, and the facility is supplied with several underground and overhead utilities. Access to the Ellis Street facility was by three entrances from Ellis Street, and an interbuilding access from an adjacent Raytheon plant on Middlefield Road to the south of the Ellis Street site. Two other buildings exist on the south side adjacent to the Ellis Street site, and a soil bentonite wall forty feet deep had previously been installed on a neighboring property, at a distance of approximately twenty feet from the west property line. A multistory building exists along most of the length of the north boundary. Immediately in front of and along the sides of the Ellis Street facility the area is paved. The western half of the Raytheon property is an undeveloped open area.

SUBSURFACE CONDITIONS

The site had been thoroughly investigated by Raytheon, by drilling over 200 boreholes and installing over 100 monitoring or extraction wells to characterize the soil and ground water from a hydrogeological and chemical point of view. Most of the investigations were oriented to chemical identification, and sampling was performed with a 3.0 inch O.D. California drive sampler, to provide six inch long samples for chemical analysis using an on-site gas chromatograph. The chemicals detected were essentially volatile organic compounds (VOC), in concentrations less than 37 parts per million (ppm) in the soil in the vicinity of the slurry wall and less than 200 mg/l in the ground water (Golder Associates, 1987). The chemicals detected most frequently were trichloroethylene (TCE) and 1,2-dichloroethylene (1,2-DCE).

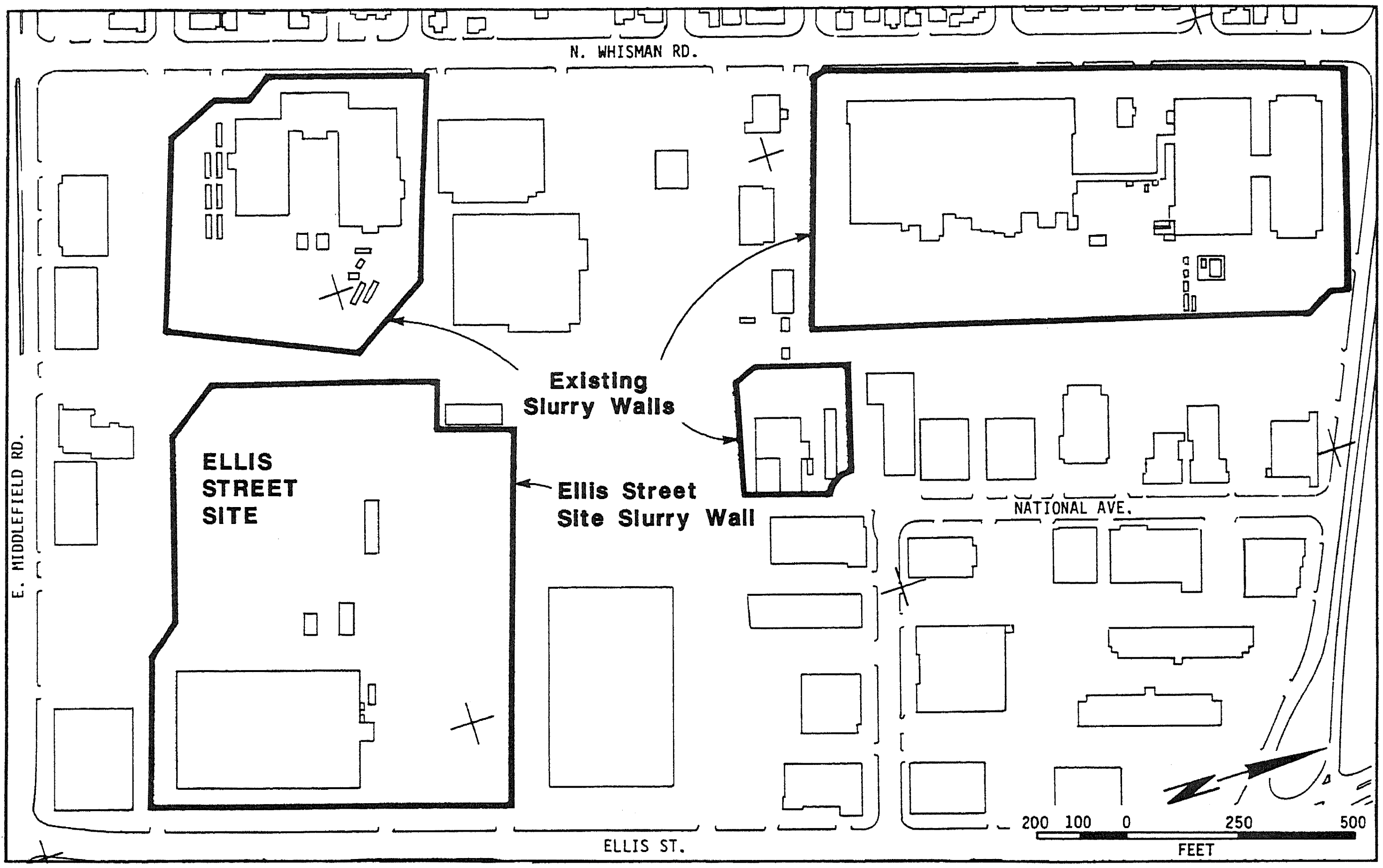

FIGURE 1. Site Vicinity Map

Investigations at the Ellis Street site and at neighboring facilities show the area to be underlain by a complex succession of medium dense to dense interbedded clays, silts, sands and gravels.

The grain size distribution of soil samples have a D_{60} (the grain size diameter larger than 60 percent of a soil sample by weight) between 30 and 0.02 mm and a D_{10} between 0.5 and less than 0.0006 mm. The fine grain samples have Atterberg limits above the "A" line.

A typical interpreted soil section through the site is presented in Figure 2. The continuity, thickness, and areal extent of the strata are highly variable, with many units thinning or pinching out. In general, the soils beneath the site can be categorized into five major water bearing zones; A, B1, B2, B3, and C (Figure 2).

Prior to construction, the groundwater surface was approximately twenty feet below ground surface with the horizontal hydraulic gradient generally to the north in all aquifer zones. The vertical gradients were upward within the A and B aquifer zones, but downward across the B/C aquitard due to pumping for water supply from the C aquifer. With the possible exception of the B/C aquitard, all other aquitards are considered to show some degree of interconnection and leakage.

SLURRY WALL DESIGN

Based upon the results of the extensive investigations at the site, a number of alternatives were evaluated for Interim Remedial Action, including excavation, groundwater control, and slurry wall with pumping from within the contained area. The installation of a slurry wall, together with pumping to maintain inward and upward hydraulic gradients was considered the best alternative to satisfy the objective of stopping further migration of chemicals from the site, protecting underlying aquifers and facilitating removal of possible chemical sources in saturated soils beneath the site. An additional important requirement was that the plant remain operational during all stages of construction and operation.

Conventionally, slurry walls have been tied in to a less permeable horizon for containment. After reviewing and assessing the site data, it was decided that this would not meet the remedial objectives. A novel concept was therefore developed in which the wall would be constructed to a predetermined depth around the site to act as a curtain within which pumping would accentuate inward and upward

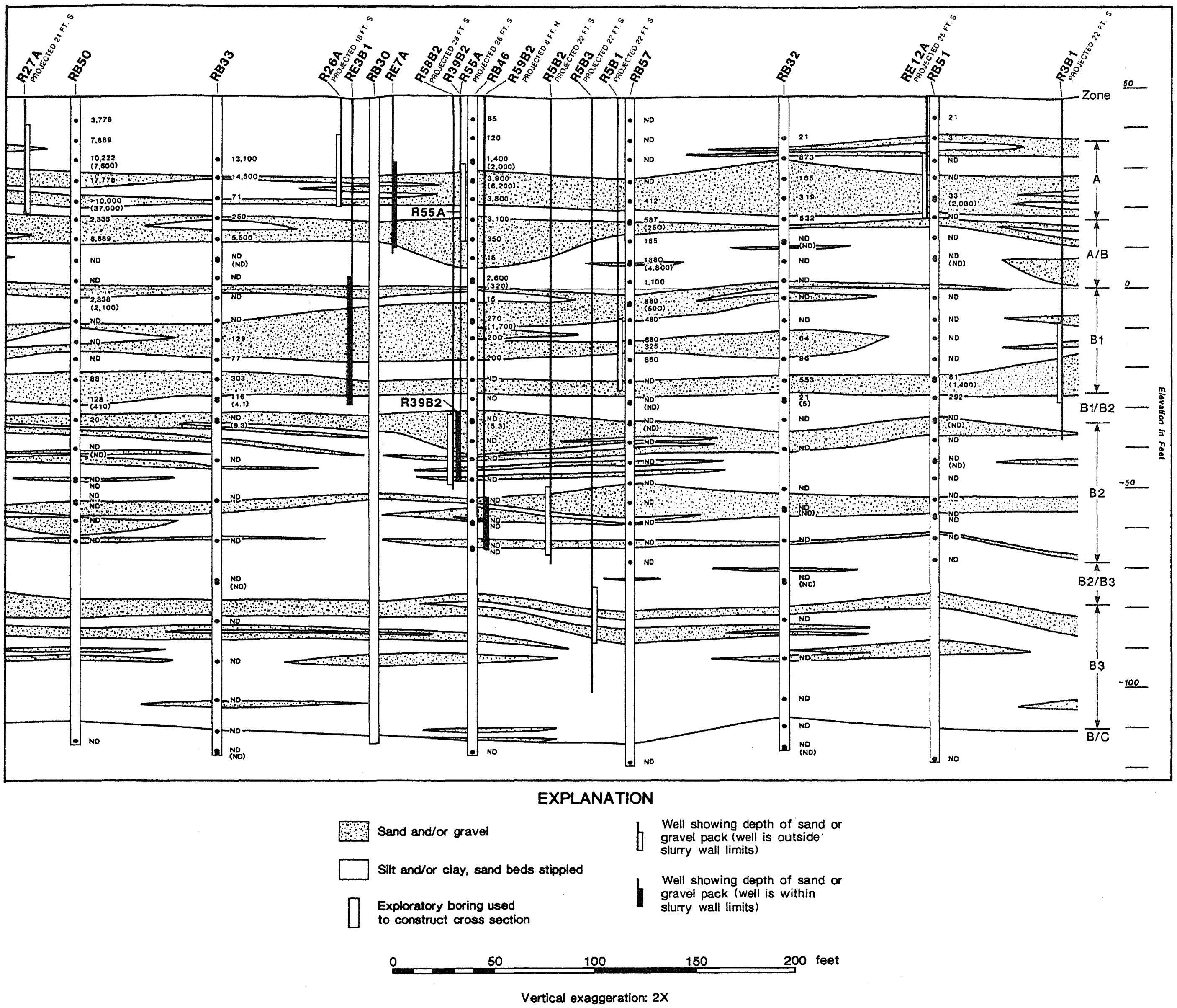

FIGURE 2. Typical Geological Cross Section (Along North Property Line)

hydraulic gradients and so stop further offsite migration of chemicals within the impacted zones (Figure 3).

Extensive design studies were undertaken, including 2-D and 3-D computer modeling of groundwater flow to confirm the utility of the novel design concept and to determine the optimum wall depth. To ensure that the wall would accentuate upward gradients across the aquitards beneath the site, it was determined that a maximum hydraulic conductivity of 1×10^{-7} cm/sec was required.

Utilities

Twenty six utilities were identified that would be affected by wall construction. In addition to water, sewerage, and storm water drainage, the Ellis Street facility is supplied with piped hydrogen, nitrogen and de-ionized water, and underground data cables linked it to an adjacent Raytheon building.

It was decided to perform utility diversions before the start of the slurry wall construction, under a contract separate from the slurry wall contract. Underground utility diversions were designed to withstand accidental impact from the slurry wall excavation equipment. Overhead utility diversions were to provide enough clearance for normal site and Contractor truck traffic, and to be demountable to allow the passage of large excavating equipment.

Potential contractors were consulted on the feasibility of utility protection. A 15 feet clearance under a utility bridge on the south

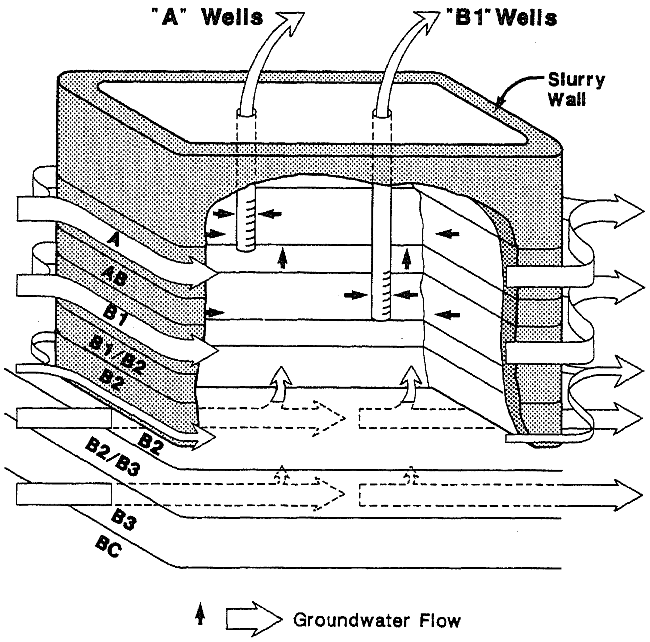

FIGURE 3. Slurry Wall Schematic

side of the site was provided, and underground utilities across the slurry trench alignment were encased in reinforced concrete sleeves. The utility conduits were consolidated to minimize separate crossings of the slurry wall. The slurry wall was located about 30 feet from the property boundary to leave enough space between construction equipment and overhead electric lines in a public utility easement around the site.

The site also contained a large number of extraction and monitoring wells that had to function during slurry wall construction. The slurry wall contractor was responsible for protecting all wells or instrumentation more than ten feet from the edge of the slurry wall. Wells within ten feet of the slurry wall alignment were abandoned by grouting in accordance with the requirements of the Santa Clara Water District.

Specifications

A considerable amount of effort went into the preparation of the specifications for the slurry wall construction particularly as there was no published precedent for slurry wall construction in constraints of the kind at the Ellis Street facility. It was decided from the outset that wall construction should be carried to a minimum performance specification for the wall materials, and that the Contractor would be responsible for providing a detailed and thorough QA/QC program.

The bentonite slurry in the trench was specified to have a minimum density of 70 pounds per cubic foot (pcf) instead of the usual 65 pcf in order to reduce potential ground movements during excavation. Bentonite was to be stored in two lined ponds, so that it would be easier to clean out the ponds at the end of the work.

Prior to the issue of the final bid documents, tests were performed to demonstrate that it was possible with the materials on site to provide a mix meeting the maximum permeability requirement of 10^{-7} cm/sec. The specifications defined a minimum bentonite content of two percent for the final soil bentonite mix, but gave the Contractor the responsibility for the mix composition to meet the specified maximum permeability. The wall width was defined as a minimum of three feet, to a depth of 100 feet. The wall had to be horizontally continuous, and the specifications required excavation and backfilling operations to be separated by a distance of at least 50 feet. The specifications allowed the Contractor the freedom to decide on equipment, although it was anticipated that he would use a backhoe and clamshells. Backfill was specified to be placed from the surface, which is usual for this kind of slurry wall.

The contract documents required that only excavated soil with VOC concentrations less than 0.5 ppm could be used in the backfill. This was to avoid the potential for introducing chemicals below the areas currently affected. The extensive investigations undertaken prior to wall design, with boreholes as close as 75 feet and samples and chemical analyses every 5 feet, provided the designers with a comprehensive picture of the vertical and lateral distribution of chemicals along the wall alignment. There was also provision in the contract documents for field checking by the Engineer, using an organic vapor analyzer (OVA).

The Engineer's method to evaluate VOC content involved mixing prescribed volumes of soil and distilled water in a glass jar. The head space above the mixture was sampled with the OVA and injected into the gas chromatograph (GC). A strip chart recorder provided the signatures of the chemicals in the soil sample which were then compared to chromatograms of standard solutions of TCE and 1,2-DCE. Actual soil concentrations were calculated by peak height comparison with these standards. Before actual excavation began, a field program was performed, with samples tested with the OVA and at an independent laboratory using the EPA method 8010 for independent confirmation.

In view of the sensitive equipment installed in the Ellis Street facility and other buildings, the specifications set maximum vibration levels at the buildings that were not to be exceeded. Vibrations were monitored for construction activities that took place approximately 100 feet away from the sensitive buildings. The maximum allowable vibration levels are given below:

Frequency	Acceleration
> 500 Hz	2.0 g.
50 - 500 Hz	1.0 g.
5 - 50 Hz	0.2 g.
shocks	2.0 g. for 10 milliseconds

Concern was expressed for the problems that could arise from dust produced by construction. After considerable research, it was decided to adopt the Environmental

Protection Agency (EPA) opacity standards used for smoke stacks, with a maximum intensity of 20 percent.

One of the most important practical consequences of the site being on the NPL was that the wall construction would be under 29 CFR Part 1910, which requires health and safety training for all persons involved in site work. The specifications required all persons on site to have level D safety protection, with equipment available for all persons to wear level C protection. Each employer was made responsible for the health and safety of his own staff.

It was made a condition of the contract that no hazardous material could leave the site. Although the work would be performed in summer, when rainfall was usually negligible, allowance had to be made to contain run off from an exceptional storm. Calculations were made to estimate the surface run-off from a storm with a 25 year recurrence interval. The potential for run-off led to the requirement to isolate the site with a earthen berm three feet high. The design therefore included sumps for stormwater collection, with a pumping system to transfer the water to lined ponds with a total capacity of approximately 3,900 cubic yards. Provision was made for the collected water to pass through settlement tanks and be aerated to remove any VOC before being discharged into the sewer system. As it turned out, the summer was dry, and no run-off had to be collected.

Quality Assurance

The specifications defined the minimum QA/QC testing to be performed by the Contractor. The Engineer reviewed the Contractor's QA/QC test results and independently verified these results by performing separate tests. Another consultant reviewed the test results of the Contractor and the Engineer and performed additional permeability tests.

No acknowledged QA/QC program existed for EPA Superfund sites (JRB Associates, 1984), and therefore a high testing frequency for monitoring workmanship and material properties, particularly permeability was required. The minimum QA/QC requirements are shown in Table 1. For the first two weeks of excavation and backfilling, the materials testing frequencies were doubled. The philosophy was to be able to identify any non-compliant materials or workmanship as early as possible, and have records available to show where any such materials may have been placed.

Before excavation could begin, the Contractor had to provide a detailed QA/QC plan defining testing and remedial actions for non-compliant materials. The Engineer also provided a QA/QC plan that was reviewed by the independent consultant. The Contractor was required to provide a qualified person, specifically for the QA/QC and his qualifications were to be approved by the Engineer. The Engineer had four employees on site to observe the construction.

TABLE 1. Slurry Wall Quality Assurance/Quality Control Testing Specifications

SOIL BENTONITE WALL

	Subject	Standard	Type of Test	Frequency	Specified Values
MATERIALS	Water	-----	pH Total Hardness	Per water source or as changes are evident	As required to properly hydrate bentonite with approved additives
	Bentonite	API 13A	All tests needed to show compliance to API 13A	1 per truckload	Premium grade sodium catopm montmorillonite
	Clay	ASTM D1140 (modified)	% Passing #200	1 per 500 cy at least once/shift	As measured
		ASTM L.L. D423 P.L. D424	Plasticity Index	1 per 500 cy at least once per/shift	As measured
SLURRY	Ponds	API Std. 13B	Viscosity	2 per shift/pond	Min. 40 sec. Marsh @ 68F
			Unit Weight	2 per shift/pond	Max. 85 lb/cu. ft. Min. 63 lb/cu. ft.
		API Std. 13B	Filtrate Loss	1 per shift	Loss <25 cc in 30 min. @ 100 psi
	Trench	API Std. 13B	Viscosity	2 per shift	Min. 40 sec. Marsh
		API Std. 13B	Unit Weight	2 per shift @ two elevations	Max. 85 lb/cu. ft. Min. 70 lb/cu. ft.

TABLE 1 (Continued)

SOIL BENTONITE WALL

	Subject	Standard	Type of Test	Frequency	Specified Values
BACKFILL	Trench	See Section 2.9.2	Permeability (laboratory)	1 per 500 cy, at least once per shift	10^{-7} cm/sec
			Permeability (field)	10 in situ tests plus one lab test on sample taken from each in-situ test location	10^{-7} cm/sec
	Trench	ASTM C-143	Slump	1 per 200 cy and at least once per shift	3" minimum - 7" maximum
	Trench	See Section	Bentonite Content	1 per 200 cy and at least once per shift	2% dry weight of backfill
	Trench		Unit Weight	1 per 200 cy at least twice per shift	15 lb/cu. ft. slurry unit weight
TRENCH	Trench	See Section 2.9.2(D)	Slope	1 per week	No irregularities which are not backfill
	Profile		Depth measurment	Per 10 LF of excavation	Min. specified key depth
	Continuity		Movement of excavation tools	Each Panel	Continuous trench
	Key		Examine cuttings	Continuous during key	Competent aquaclude material

The Contractor established an on site laboratory, equipped to perform all the tests in Table 1. Most of the tests were standard for the permeability tests the consolidation pressure, hydraulic gradient, apparatus type, and permeant were specified. The Engineer maintained an independent, fully equipped on site laboratory, and performed testing at approximately one half the frequency required of the Contractor.

Slurry trench depths were verified at ten feet horizontal intervals. The Contractor maintained a large scale elevation drawing of the wall, showing excavation and backfilling progress on a daily basis to enable any materials found later as non-compliant to be located.

The specification provided a list of reporting items, to be provided in weekly reports. Any non-compliant items were discussed at daily progress meetings with the Owner, Engineer and Contractor.

Instrumentation

Three inclinometers; accelerometers for vibration monitoring in the x, y, and z directions; and a number of settlement points were installed around the site. To assess the ground movement around neighboring buildings, the inclinometers were placed inside the slurry wall equidistant from the wall as the buildings of concern or in between the wall and the building. The first inclinometer was placed near the starting point, in order to have early information on ground movements. The inclinometers were read as part of the Owners QA/QC, and the results were reviewed by the Engineer.

The inclinometers were of the Sinco type, with 10 foot long casings 3 inches in diameter. The inclinometers went to a depth of 150 Feet, and were surrounded by a grout mix approved by the Santa Clara Water District, for imperfect sealing could lead to communication between the aquifers.

SLURRY WALL CONSTRUCTION

Slurry wall construction began in June 1987, and the wall was completed by the end of October. The Contractor used a backhoe with an extended boom to excavate the trench to a depth of approximately 50 feet. Two 200 ton Manitowoc cranes were used with the 12 ton clamshells, to excavate the trench to a depth of 100 feet. The wall perimeter measured over 3400 feet.

Backfill was mixed in a mixing pit, by placing a volume of excavated soil that had been mixed with slurry in a pit of known volume. The bentonite was added from sacks submerged in the pit, which considerably reduced the problems associated with dust. The backfill was mixed in the pit with a backhoe, which was also used to load the final mix into trucks. The trucks then transported the backfill to the slurry trench, where it was end dumped onto the exposed backfill already in the trench. This caused the backfill to enter the trench by continuous failure of the backfill slope, and thus minimized segregation and the chance for incorporating slurry pockets in the backfill. This method of handling the excavated soil and backfill kept the site relatively clean. Tarpaulins were placed over the facades of adjacent buildings, and no complaints were received from the public on site cleanliness. At the end of wall construction, the excess soil was stockpiled and the slurry was left in the lined ponds.

Construction of the slurry wall beneath the buried utilities was performed carefully, and it is to the Contractor's credit that not one utility was damaged. After the start of construction, the sequence of excavation was changed at the request of the Owner. This required the Contractor to use bulkheads of soil to support different elevations of slurry in the trench across the site where there was a difference in grade of more than four feet. Actual wall construction led to the phasing shown in Figure 4. The excavation sequence required considerable coordination between the Contractor and the Owner to ensure the facility with all of its traffic could remain in operation. Construction was completed on time and within budget, with no major breakdowns or mishaps.

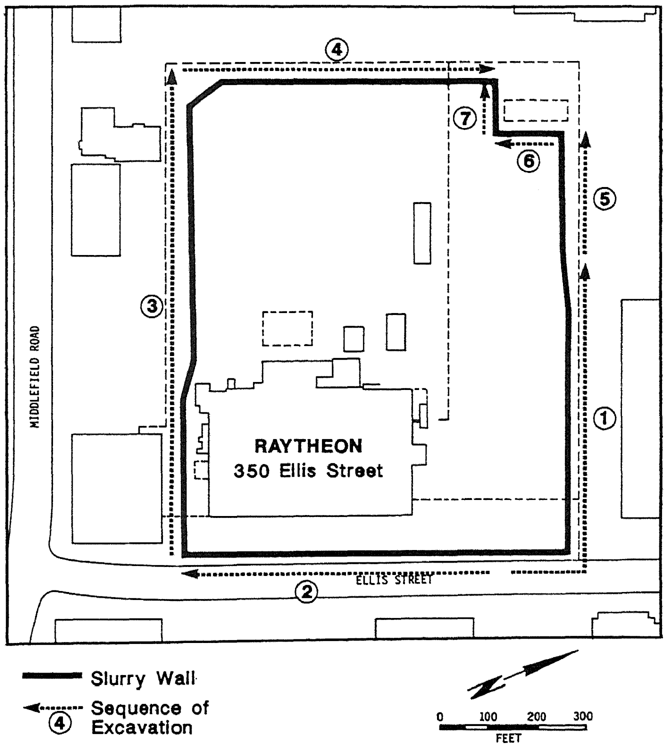

FIGURE 4. Slurry Wall Excavation Sequence

The results of the QA/QC showed that no non-compliant material was in the wall backfill. All the permeability test results, which are shown on Figure 5, were well below the required maximum.

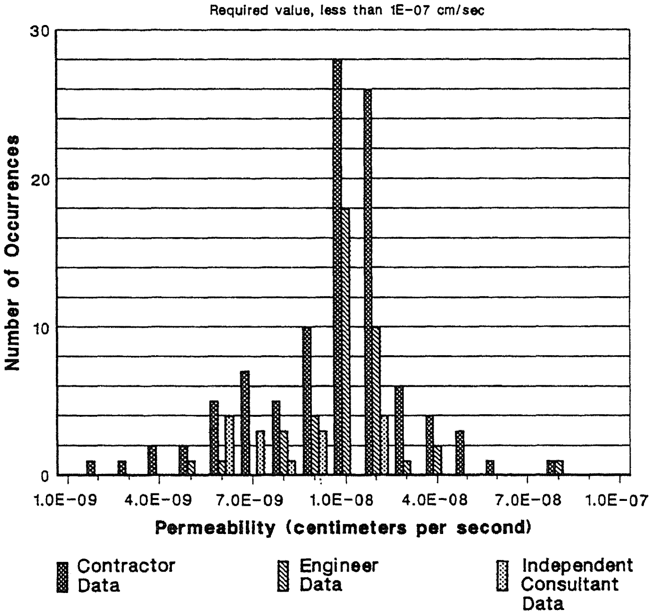

FIGURE 5. Histogram of Permeability Test Results by Laboratory

Measurements of actual soil VOC content, as performed on the excavated soil, showed an excellent correlation with the anticipated concentrations based upon boreholes along the wall alignment. Airborne VOC levels were monitored for health and safety purposes, and level C protection was not required at any time.

Inclinometer movements showed up to 0.8 inches of movement towards the trench during excavation, followed by an outward movement below 20 feet depth after placing the backfill. Inclinometers have shown movement towards the trench subsequent to placing the backfill.

Slurry Wall Effectiveness

The effectiveness of the slurry wall was demonstrated during the construction, based upon water level measurements in the monitoring wells. Deep well pumping continued during wall construction, and water levels in the pumped aquifers within the contained area dropped as soon as the wall was near completion.

CONCLUSIONS

Extensive QA/QC testing has indicated that the slurry wall meets the specified maximum permeability requirements, and will prevent further offsite migration of chemicals in groundwater. Careful planning and close liaison between the Owner, Engineer and Contractor has enabled slurry wall technology, usually applied in a less restrictive setting, to be used around an operating manufacturing facility, without disruption to production.

Acknowledgements

The successful result of the project is due to excellent co-operation between the Owner, Raytheon Semiconductor Company; the Engineer, Golder Associates, Inc.; the Owner's QA/QC engineer, Harding Lawson Associates; and the Contractor, GKN-Hayward Baker. The views expressed in this paper are those of the authors, and do not represent those of the above mentioned organizations.

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