RESEARCH PAPER

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Slurry Wall Standards

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INTRODUCTION

> Since the inception of [slurry wall techniques] in the 1940's, slurry cutoff walls have been used where relatively unpolluted groundwater was diverted for civil works such as dams, dikes and dewatering structural excavations. With the beginnings of CERLA [Comprehensive Environmental Response, Compensation and Liability Act] legislation and the environmental movement of the 1970’s, more and more slurry cutoff walls are built to contain contaminated groundwater at landfills, hazard waste and industrial facilities.[1]

In addition to their important use as underground barriers, slurry walls serve many other critical functions. This paper examines the use of slurry wall technology and the voluntary standards associated with slurry wall fabrication.

WHAT IS A SLURRY WALL?

Slurry walls are narrow, deep trenches filled with a clay-water mixture (referred to as "slurry") as part of the construction process. The slurry is usually composed of a bentonite-water mixture, although polymer slurry mixtures are sometimes used to minimize concrete-slurry mixing. Bentonite is a form of impure clay. The use of slurry serves two important functions. First, the hydraulic pressure exerted by the slurry mixture helps to prevent the narrow slurry wall trench from collapsing during construction: the slurry mixture is pumped into place during the excavation process, and remains there until it is displaced with concrete during the final phases of construction. Second, the slurry helps to minimize equipment strain by lubricating excavating equipment and softening the ground for ease of removal.

Slurry walls have been widely used because they are highly stable, relatively inexpensive, and quickly constructed. Moreover, slurry wall construction equipment is relatively non-evasive, allowing construction in the tight confines of dense metropolitan areas. Besides their environmental containment applications, properly constructed slurry walls can accept large vertical and horizontal loads. The designers of Boston's Central Artery/Tunnel (CA/T) project−widely accepted as the most complex highway and tunnel project in the nation's history−applied slurry wall technology extensively. Slurry walls were used to support the antiquated sections of Interstate 93 while a modern expressway was tunneled under the city. Maintaining the city's main thoroughfare open during tunnel construction was critical to preserving the city's economic vitality. Additionally, the slurry walls formed the sides of the underground tunnel and prevented cave-ins during construction.

Slurry walls technology was used extensively at the World Trade Center (WTC) site during construction in the 1960s. A slurry wall 3 feet thick and 80 feet deep was constructed around the WTC site to create a "bathtub," a deep water-tight pit below the water table, which formed the foundation for the WTC buildings. When the WTC towers were destroyed on September 11th, the slurry walls survived and prevented portions of New York City from flooding. Clearly, slurry wall construction applications are critically important to society.

THE DEEP FOUNDATIONS INSTITUTE

The Deep Foundations Institute (DFI) is extremely interested in slurry wall construction. DFI is a non-profit educational activity based in New Jersey. Although most of its activity is in North America, it does have some worldwide membership. DFI is a technical association of firms and individuals in the deep foundations and related industry (http://www.dfi.org/about.asp). DFI recognized slurry wall technology as an important infrastructure-development tool and organized a slurry wall technical committee to develop applicable standards. The Deep Foundations Institute Slurry Wall/Trench Committee is comprised of 14 members, representing 11 independent, international organizations; all on the cutting-edge of slurry wall technology. The Committee preserves the global relevance of its publications through the quality and diversity of its membership. Membership includes the Treviicos Corporation (an Italian company founded in 1957), who pioneered early slurry wall fabrication techniques in Europe and North America. Another corporate member, Mueser Rutledge Consulting Engineers, perfected the ground freezing techniques critical to Boston's Central Artery/Tunnel project. Another member, Weidlinger Associates, Inc., helped design and manage the construction of the Cheju World Cup Stadium in Sogwipo, Korea. Clearly, DFI has global appeal.

DEEP FOUNDATIONS INSTITUTE PUBLICATION 74

> This publication...is intended to provide the industry with model practice guidelines for design and construction of structural slurry walls...it is a composite of the opinions of practicing engineers, construction experts and the DFI Slurry Wall/Trench Committee.[2]

Deep Foundations Institute (DFI) Publication 74 (entitled *Industry Practice Standards and DFI Practice Guidelines for Structural Slurry Walls*) is a 102 page document that was published in May, 2005 by the Deep Foundations Institute. Deep Foundations Institute Publication 74, hereinafter referred to as DFI 74, established an industry standard for slurry wall construction (available at www.dfi.org for approximately $30). The document's preface identifies the DFI Slurry Wall Committee members, defines a slurry wall terminology, and provides a history of slurry wall construction. DFI 74 contains six parts.

Part I (Industry Practice Standards) classifies structural slurry wall construction elements; for example, typical sizes of slurry wall panels, panel depths, equipment, slurry fluids, phases of construction, inspection, records and final condition observations. Part II (DFI Practice Guidelines) briefly describes acceptable contractor qualifications, sub-surface and site inspection adequacy, and site-specific design considerations. Other areas covered include schedule submittal requirements, preparations for excavation, concrete placement considerations, and water tightness criteria. Part II also provides important material specifications: for example, "Concrete should meet the specified minimum compressive strength (f'c) at 28 days, usually between 3000 psi and 5000 psi, at a slump ranging between 7 and 9 inches."[3] Slurry specific handling and concentration criteria are also listed. In many places DFI 74 references other standards: for example, "Steel reinforcement should consist of new deformed billet steel bars conforming to the requirements of ASTM A615, Grades 60 and 75...."[4]

Part III is dedicated to definitions. Here, for example, API Specification 13A is defined (i.e., the American Petroleum Institute specification for oil well drilling-fluid materials). In this section industry specific definitions dominate (e.g., porcupine plate, go devil, plastic concrete, tieback, etc.), although more common construction terms are also addressed (e.g., load bearing element, preload, sand content, etc.).

Part IV contains a series of illustrated figures: for example, slurry wall panel configurations, blank slurry fluid test report forms, slurry wall tolerances measurement diagrams, and slurry wall construction equipment. Interestingly, although ISO 22242 (Road Construction and Road Maintenance Equipment and

Identification) provides similar construction equipment configurations, it is not referenced in DFI 74.

Part V (Additional Information) provides a list of reference material. The diversity of references suggests DFI is attempting to appeal to a broad target audience. References include British Standards Institute publications, academic textbooks, a diverse set of meeting proceedings, and many other technical documents. Part VI contains a list of completed slurry wall projects–in North America from 1960 through 2005. For each project a brief description is provided as well as wall thickness and project size. The District of Columbia, Boston, and New York stand out as the having the densest concentration of slurry wall projects in North America.

OTHER SLURRY WALL STANDARDS

Although DFI 74 has global relevance, global acceptance will take some time. First, it is a relatively new publication. Second, DFI 74 alludes to international construction proclivities but does not reference any specific international standards (e.g., ISO standards). For example, "unlike U.S. practice, some European contractors [elect] to not use guide walls, but rely on the crane's controls having gyroscopes and inclinometers to guide the clamshell equipment and to indicate the depth of the excavation and twist of the bucket."[5] Third, DF 74 is available only in English. For these reasons, its global appeal may be limited in the short-term. Notwithstanding these roadblocks to global acceptance, DFI 74 is the most comprehensive slurry wall standard available considering there is no single code, even in the U.S., that fully applies to all slurry wall applications.[6]

Geo-Con, a Pennsylvania based geotechnical contractor, offers its own–albeit less comprehensive–slurry wall technical specifications in the form contract writer's guide (entitled *Technical Specifications: Soil-Bentonite Slurry Trench Cutoff Wall*). This organically developed document was designed for company use only (i.e., Geo-Con engineers and other contract writers). It references many API and American Society for Testing Materials (ASTM) standards and parallels much of the information found in DFI 74: it discusses contractor qualifications, slurry trench minimum dimensions, slurry composition, construction techniques, and quality control methodology. Comparing DF 74 to Geo-Con's document highlights two important points: (1) broad acceptance of standards associated with such a diversely applied technology is difficult and (2) DFI 74 represents one of the more all-encompassing attempts to standardize the practice of slurry wall construction.

DFI'S STANDARD DEVELOPMENT PROCESS

The DFI by-laws provide insight into its nature as a standards setting organization. The language contained in the DFI by-laws reflect the principles for standards development published in the United States Standards Strategy.[7]

Article II of the DFI by-laws states that DFI was organized “to serve as a primary means [to improve] the planning, design and construction aspects of deep foundations and deep excavations.”[8] This suggests that DFI is interested in maintaining its credibility and industry relevance. Article IV, Section 7 of the DFI by-laws addresses voting rights: “Each individual member and corporate delegate [of a technical committee] shall be entitled to one vote.”[9] This policy is well aligned with the United States Standard Strategy approach to standards development. Specifically, the one-member-one-vote policy prevents one interest from dominating the process. Article IV, Section 8 defines a two-thirds vote as the majority vote required to remove members for conduct prejudicial to the interests of the institute, but dictates a “right to notification” and “right to be heard” for those facing removal proceedings. Article V, Section 4 defines the number of members that constitute a "meeting quorum"; Section 5 mandates a 30 day written notification prior to all committee meetings. Moreover, representation on a DFI committee is not restricted to DFI membership: Article XIV, Section 3 addresses inclusion of non-member experts in special committee proceedings (each with full voting rights). All of this language suggests that the DFI values a set of recognized principles for standards development: relevance, transparency, openness, impartiality, and consensus.

THE VALUE OF SLURRY WALL STANDARDS

Construction and performance standards are important because slurry walls serve critical functions. Leaks in Boston’s CA/T project tunnel demonstrate some the consequences of improper construction. Boston's CA/T project represented the largest single use of slurry walls in North America. Tunnel performance, however, was maligned since the early days of construction. George J. Tamaro, one of the world’s top tunnel experts, remarked that a particular section of tunnel wall “fell woefully short of basic professional and contractual standards.”[10] Jack K. Lemley, an internationally known consultant hired by the Massachusetts Turnpike Authority, concluded that the leaks “were primarily the result of pockets of extraneous materials, such as sand, gravel or clay lodged in the tunnel’s concrete walls.”[11] These leaks forced sections of Interstate 93 to be shut down causing massive delays and large cost overruns. In July, 2006, a motorist was crushed when tiebacks holding large concrete panels failed causing several concrete ceiling panels to fall. Although this tragedy was not linked to the quality of slurry wall construction, it does highlight the value of good quality control standards.

Slurry wall technology could potentially benefit portions of the Gulf Coast ravaged by hurricanes Katrina and Rita. To this effect, the Deep Foundations Institute’s Slurry Wall Committee is currently planning a one day seminar to take place in the late fall of 2006 to share information on projects that involve repair and rehabilitation of waterways, dams and marine structures damaged by the storms. Properly constructed slurry walls benefit society. It logically follows, therefore, that conformance to slurry wall standards is critical to realize those potential benefits.

FEDERAL REGULATION

Associated regulation is primarily focused on the use of slurry walls as environmental barriers, specifically their ability to stabilize pockets of ground contamination. There are three major pieces of federal regulation that deal with hazardous waste and toxic substances: the Resource Conservation and Recovery Act of 1976 (RCRA); the Toxic Substances Control Act of 1976 (TOSCA); and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980. Of these three federal regulations, the CERCLA (commonly known as Superfund) most closely relates to slurry wall construction.

> One of the earliest uses of slurry walls in EPA's Superfund program was at Brodhead Creek Site in Pennsylvania. The 12-acre site is the location of a former coal gasification plant which operated along the west bank of Brodhead Creek in the Stroudsburg, Pennsylvania. In 1981, EPA took steps to stop the seepage of coal tar from the site into the creek by constructing an underground cement-bentonite slurry wall.[12]

Superfund legislation taxes chemical producers and provides broad federal authority to respond to hazardous chemical releases, specifically those that pose a risk to the public health or the environment. Superfund was amended in 1986 to better leverage state and local environmental laws.[13] It makes sense that EPA is interested slurry wall construction and performance standards. In 1998 the EPA published its research findings on several dozen slurry wall sites. "[The EPA's] designation of acceptable industry practices was based on a literature review, reinforced by discussions with barrier construction contractors, designers of barriers, university researchers and the best professional judgment of the project team."[14] The EPA recognized that performance objectives varied among sites which made comparison to an absolute slurry wall standard impossible. Of the 36 sites evaluated, 25 met performance objectives; the rest failed or were questionable, a failure percentage large enough to raise eyebrows. Although the EPA does not regulate slurry wall construction, per se, the government does recognize slurry wall barriers as an important tool for protecting the environment. One of the major tenants of the Superfund legislation was to hold those responsible for violations financially accountable for remediation. To assist with program administration, the federal government is leaning more and more on state and local legislation and enforcement. An examination Colorado law illustrates this.

COLORADO STATE REGULATION: A CASE STUDY

> From the perspective of the casual observer, slurry wall methods may look crude and prone to variability of the end

> product. Actually, standard methods, when properly executed under the guidance of knowledgeable slurry specialists, produce an effective low-permeability barrier at low cost. Nevertheless, engineers are constantly looking for better ways to control the process and to ensure the quality of the end product.[15]

Slurry wall regulators are primarily concerned with a wall's ability to contain hazardous waste (i.e., permeability). Although DFI 74 is one of the most comprehensive slurry wall standards available, its primary focus is on structural construction, not permeability. Slurry wall permeability standards do exist however. The Colorado State Engineer's Office, for example, established design and performance standards for slurry walls constructed in that state. In Colorado, "it has become common practice to reclaim gravel pits to develop water resource land use through the installation of…slurry walls."[16] Moreover, under Colorado state law, it is the responsibility of the state's Mined Land Reclamation Board to hold "sufficient bond to assure that the State Engineer's performance standard can be met if the Operator [sic] of a pit were to default and the state of Colorado were to reclaim the site with the forfeit bond."[17]

The pit operator has two construction bonding options: he may elect to bond for 100 percent installation cost of the slurry wall or he may elect to a regulated construction option, paying just a 20 percent installation bond. The latter option requires the operator to obtain state approval of design documents, which are then considered "enforceable components of the reclamation permit."[18]

In either case, the operator forfeits the bond if the State determines that the wall does not meet their performance specifications. The 100 percent bond option provides for more construction flexibility but the contractor assumes more of a financial risk. The 20 percent bond option risks less money but at the expense of increased government regulation. In either case, bond money is returned when the finished product meets the State Engineer's performance standard or is forfeited to the State if it does not.

Colorado's <u>construction</u> standard is a voluntary standard. Associated regulations were carefully worded so as not to "stifle the flexibility" applicants have to design their slurry wall. On the other hand, Colorado's slurry wall <u>performance</u> standard is regulated by the State. Nevertheless, Colorado regulators understand the unpredictable nature of slurry wall construction so they allow pit operators to share the inherent risk associated with construction:

> Slurry cutoff walls are susceptible to failure during construction and operation as a result of groundwater contamination. Because of the specialized nature of the construction process, the materials selected for the installation must meet workability restraints. In practice, this means that the materials must be suitable for the specialty contractors' requirements as well as the designers' objectives for the installation to be effective.[19]

It is clear that the State understands potential slurry wall failure mechanisms: Colorado has developed regulation that shares those risks, ultimately benefiting the environment and, therefore society. Applicable Colorado laws were adroitly developed so as not to limit designer flexibility yet still positively connect construction methods with proven slurry wall standards.

CONCLUSION

Slurry wall construction techniques have been evolving for hundreds of years. Their use is economical, non-evasive, quick, and effective. Although other standards exist, DFI 74 is the most comprehensive slurry wall standard available. It was developed by experts using the globally accepted principles for standards development. Federal law does not regulate slurry wall construction but does delegate some aspects of anti-pollution enforcement to the state and local level. It is not unreasonable to predict that DFI 74 could be referenced in future federal and state legislation. There is one certainty though: as the use of slurry wall technology increases, so too will the value and importance of slurry wall standards.

ENDNOTES

[1] Steven R. Day, *The Compatibility of Slurry Cutoff Wall Materials with Groundwater*. Retrieved July 15, 2006, from the World Wide Web: http://www.geocon.net/pdf/paper22.pdf, 2.

[2] Deep Foundations Institute. *Industry Practice Standards and DFI Practice Guidelines for Structural Slurry Walls*. 1st ed. Published by the DFI Slurry Wall/Trench Committee, i.

[3] Ibid, 25.

[4] Ibid, 25.

[5] Ibid, 9.

[6] Ibid, 23.

[7] United States Standards Strategy Committee. *United States Standards Strat*egy. Published by the American National Standards Institute, 2005.

[8] Deep Foundations Institute website: http://www.dfi.org/bylaws.asp.

[9] Ibid.

[10] Sean P. Murphy and Raphael Lewis. "Big Dig Found Riddles With Leaks." *The Boston Globe*, 10 November 2004.

[11] Ibid.

[12] Portland Cement Association website: http://www.cement.org/waste/wt_apps_super.asp.

[13] U.S. Environmental Protection Agency website: http://www.epa.gov/superfund/action/law/sara.htm.

[14] United States Environmental Protection Agency. (1998, August). *Evaluation of Subsurface Engineered Barriers at Waste Site*s. Retrieved July 8, 2006, from the World Wide Web: http://207.86.51.66/download/techdrct/tdsubsrf.pdf, vii.

[15] Christopher R. Ryan and Steven R. Day. *Soil-Bentonite Slurry Wall Specifications*. Retrieved July 8, 2006, from the World Wide Web: http://www.geo-solutions.com/pdf/TP-PANAM-SBSpecs03.pdf, 1.

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[16] Colorado Department of Natural Resources Division of Minerals and Geology. *Guide to Specification Preparation for Slurry Walls and Clay Liners as a Component of Colorado Mined Reclamation Permit*. Retrieved July 8, 2006, from the World Wide Web:http://mining.state.co.us/rulesregs/ LINEDPITGUIDE.pdf,1.

[17] Ibid, 1.

[18] Ibid, 1.

[19] Geo-Con. Steven R. Day, *The Compatibility of Slurry Cutoff Wall Materials with Groundwater*. Retrieved July 15, 2006, from the World Wide Web: http://www.geocon.net/pdf/paper22.pdf, 3.

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