TECHNICAL GUIDANCE DOCUMENT

INDIANA DEPARTMENT OF ENVIRONMENTAL MANAGEMENT

ENGINEERING CONTROL: SLURRY WALLS

Office of Land Quality

(317) 232-8941 • (800) 451-6027 www.idem.IN.gov 100 N. Senate Ave., Indianapolis, IN 46204

Guidance Created: October 12, 2010
Guidance Updated: September 2017, and May 2021

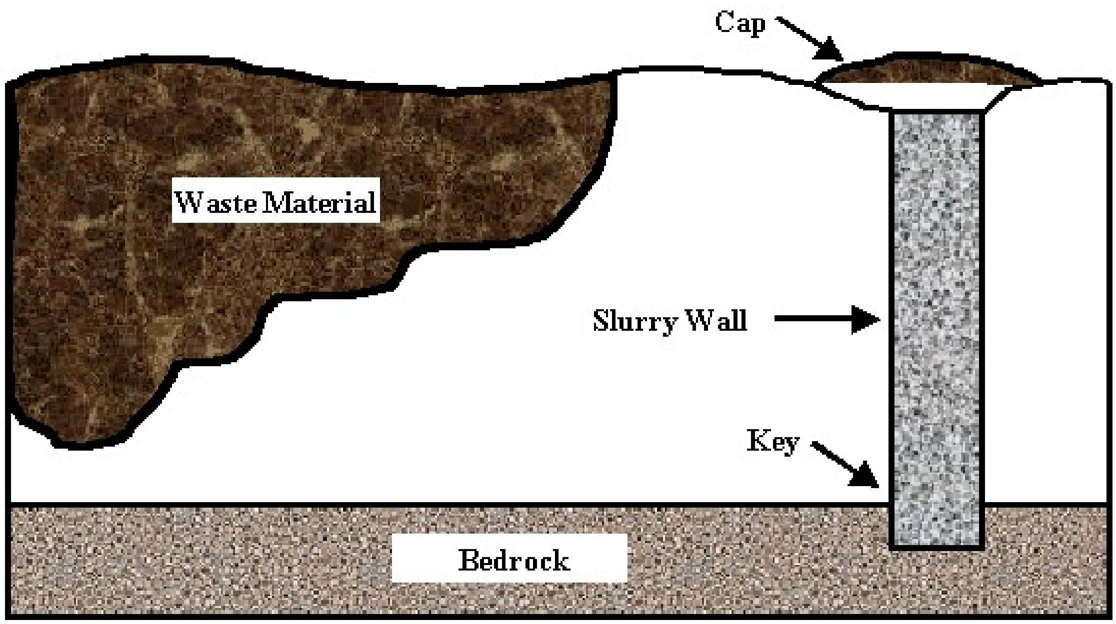
1.0 Purpose, Scope and Applicability:

This guidance provides basic design specification, operation and maintenance guidelines for containment slurry walls. Slurry walls are used as an engineering control to prevent groundwater and non-aqueous phase liquids (NAPL) migration and/or maintain separation between contaminated and uncontaminated groundwater regimes. This guidance does not intend to provide comprehensive instruction or direction on remedy selection, site-wide feasibility assessment, exposure, or risk assessment.

2.0 Table of Contents

3.0 Introduction:

Slurry walls have been used to contain contaminated groundwater for decades. They can be a cost-effective remedial measure in appropriate circumstances. Containment slurry walls operate by creating an impermeable barrier between contaminated and uncontaminated groundwater with groundwater gradient control inside the slurry wall. Slurry walls are implemented in conjunction with a groundwater pumping system to collect contaminated groundwater and also with a low permeability cap on top of the slurry wall to eliminate infiltration into the wall. The following sections provide an overview of the types and methods of slurry wall construction, applicable performance specifications, and operation and maintenance requirements.



Picture from **https://frtr.gov/matrix2/section4/D01-4-53.html** The slurry wall key must be either into bedrock or a layer of appropriately low permeability.

4.0 Design and Installation:

Slurry wall designs should be submitted by a Professional Engineer. Basic slurry wall installation consists of excavating a vertical walled trench which is subsequently backfilled with a low permeability material. The success of slurry walls as a remedial measure depends on selecting appropriate location, excavation and installation methods, slurry type and backfill specifications, key into an impermeable layer and accompanying measures such as impermeable covers and groundwater management plans. The decision to choose a slurry wall as a remedial measure should consider the continuing obligation to replace or propose a new remedy at the end of the slurry wall design life.

Location:

A low permeability slurry barrier may be upgradient of, downgradient of or completely encircle (circumferential slurry wall) contamination. Circumferential walls with a cap over the entire contaminated area are the most expensive but offer the most complete containment and result in greatly reduced leachate generation over the lifetime of the wall. Upgradient walls are somewhat uncommon and serve to divert water around contamination; they are most common in sites with steep groundwater gradients where collection would be prohibitively expensive. Downgradient slurry walls provide a means to capture contamination for treatment. Safety considerations such as trench stability, existing utilities, and the need to avoid undermining nearby structure foundations must be considered when choosing a location also.

Excavation methods:

Drilling Mud:

The most popular method of installing slurry walls is to dig a trench which is immediately filled with bentonite slurry (drilling mud) to support the excavation; the slurry is subsequently displaced with backfill which is denser than the slurry. The bentonite in the slurry mix forms a thin layer commonly called the filter cake on the trench walls due to its thixotropic properties. The filtercake has three primary functions:

1. The filtercake inhibits slurry loss from seeping through the trench walls and groundwater from entering the trench due to the low hydraulic conductivity of the filtercake;
2. The filtercake forms a vertical plane for the slurry to exert hydraulic force on the trench walls thereby keeping the trench open until backfill can be placed;
3. The filtercake stabilizes soil particles on the trench sidewall keeping them in place.

The trenches are usually dug with a hydraulic excavator. Clamshell diggers are necessary for deeper (greater than approximately 80 ft) installations. Typically, trenches built using this method are 3 ft wide.

Vibrating beam:

A second method of excavation is via a vibrated steel beam attached to a pile driver. The beam is vibrated along the slurry wall line forming a trench which is the width of the beam, typically 10 inches wide. The trench is filled with slurry as the beam is pulled out. Vibrating beams can only be installed when depth and geology allow the vibrating beam to operate without being structurally damaged.

Backfill materials:

The composition of the completed slurry wall is determined by the backfill. Backfill is usually a mixture of excavated soil, dry bentonite and bentonite slurry which forms an impervious barrier. Backfill material is generally mixed on site adjacent to the trench with earthmoving equipment until homogeneous.

In general, the soil fines content and bentonite content are the most important factors in determining the final performance of the slurry wall. Soil Bentonite (SB) backfill generally needs at least 15-20% soil fines content. A slump test is strongly recommended (ASTM D143) as a performance standardization measure. Total bentonite content by weight will determine the final permeability of the wall. Total bentonite content is from the bentonite in the original slurry, bentonite in the backfill and dry bentonite added directly. Typically, slurry bentonite concentrations are 5-7%, dry bentonite added is 0-3% and backfill bentonite contents is largely dependent on the accompanying soil specifications and whether any amendments such as cement are added. Hydraulic conductivity ASTM 5084 is usually used to assess the hydraulic conductivity of the placed backfill.

Keying:

At slurry wall base:

A primary determining aspect of any slurry wall is the 'key' into an impermeable (hydraulic conductivity $<10^{-7}$ cm/s) layer. Generally, the key extends 2-3 ft into the impermeable layer. A 'hanging wall' is not keyed in but is completed several feet into the lowest water table level and can be used to control floating contaminants.

Circumferential:

If a slurry wall is to completely encircle contamination, the final section will have to be keyed into a previously backfilled section to close the loop. The standard method is to dig through the previously placed backfill creating an overlap which should be at least 5 ft long. The thixotropic nature of bentonite allows it to be agitated and then reset without degrading the performance of the completed wall.

Amendments:

If structural strength is required, backfill amendments such as Portland cement may be necessary to obtain the required compressive strength. Soil Bentonite walls (SB) have a lower hydraulic conductivity and generally cost less than cement bentonite (CB) walls. Structural strength is generally specified using a 7-day unconfined strength test. Cement mixtures are generally used as the slurry and then allowed to harden eliminating the backfilling step. CB walls typically require more carefully timed construction methods from SB walls. Cement begins to harden after 2-3 hours; continued agitation after 24 hours inhibits the cement from setting. CB walls are sometimes constructed as a series of panels in which alternate panels are constructed under slurry and allowed to partially set before the remaining panels are trenched using the same method. The caveat to this construction method is the possibility of hydraulic leaking at the point where the panels are joined.

Chemical compatibility

Certain chemicals may degrade the wall over time such that even if it meets specifications originally, over time its integrity may erode. In particular, pure xylene and methanol have been reported to increase slurry wall conductivity two to three orders of magnitude. Chemical compatibility should be investigated before a slurry wall is chosen as a containment method. This is also an added reason that long term monitoring is necessary even if the original wall meets conductivity specifications.

Top cover~~—CAP~~

The slurry wall design should include a low permeability cover over the top surface of the slurry wall at a minimum to prevent surface infiltration. Usually the top 1 to 3 ft of slurry wall is removed and an impermeable cover placed over it.

Groundwater Management:

A groundwater management plan should be submitted with any slurry wall corrective action plan. Even in the case of circumferential slurry walls, over time, groundwater can build up and need to be addressed. An appropriate groundwater monitoring well network is required to show that the groundwater management plan is working. A one-foot differential measured across the slurry wall is often specified to indicate an inward gradient is achieved.

5.0 Performance Specifications:

Most test methods for slurry construction were originated from the oil well drilling industry and specified by the American Petroleum Institute in their Standard Procedure for Field Testing Drilling Fluids (API RP 13B). ASTM has also developed corresponding specs for most of these methods.

Since the primary purpose of a slurry wall is to impede groundwater, the primary performance criteria should center on assuring permeability specifications of the completed wall by demonstrating both a low conductivity and a lack of leaks. However, interim specifications during construction of the slurry, backfill mixture and site conditions are typically used to help ensure that the completed wall will meet specifications.

Interim Slurry/ Backfill & Construction Specifications:

Marsh Funnel Viscosity (API Code RP13B) test is used to determine the viscosity of the slurry. The typical specification is greater than 40 seconds. The viscosity of the mixture depends on the bentonite content, type of bentonite, the degree of hydration and water quality.

Density or Mud balance is generally at least 15lb/ft3 less than the density of the backfill. (API Code RP13B)

Filter Press is a test which measures water loss of a slurry under a pressure (usually 690kPa) and the thickness of the resulting filter cake. It is not particularly useful as an environmental specification as it does not give an indication of the performance of the completed wall. It is more an economic specification since a lower filtrate value would result in less loss through the trench walls of slurry wall construction materials resulting in a less expensive wall.

Visual Confirmation of the Key should be performed every 100 feet to ensure that the wall is properly keyed at least two feet into an impermeable layer. For vibrating beam installation, a boring must be taken in advance of installation and the appropriate depth of installation maintained. For traditional trench slurry walls, inspection of the excavation spoil from the trench bottom is performed.

Completed Wall Monitoring and Performance Specifications.

Performance specifications for slurry walls involve assuring that the completed wall is of adequately low hydraulic conductivity and that the wall is keyed to an impermeable layer such that leakage does not occur. Hydraulic conductivity is generally determined by sampling the backfill using ASTM D5084. In situ testing of the completed wall is difficult. The only reliable method to assess the conductivity without degrading the structure of the wall is to create a substantial test cell and do a pump test. A pump test is both expensive and time consuming but may be appropriate at some sites.

Wall integrity, key integrity and hydraulic conductivity should be assured over the lifetime of the wall with an appropriate monitoring well network. Wells screened at the key interval may be necessary depending on site conditions. An additional performance measure is gradient monitoring on both sides of the wall. An adequate performance specification is that a one foot inward gradient differential across the wall will be maintained.

Both a long-term groundwater monitoring program and the long term details of the O&M for any groundwater pumping system/hydraulic head obligations should be planned and approved before this remedy is allowed. These plans should be documented within an enforceable mechanism such as an Environmentally Restrictive Covenant, Agreed Order or Permit.

Acceptable Performance Specifications				
Material	**Test Function**	**Test**	**Specification**	**Frequency**
Interim Construction Specifications				
Slurry in trench or fresh	Unit weight or mud balance	API Std 13b	1.03 -1.36 gm/cm^3 or specify amt. less than backfill.	Twice per shift
Slurry in trench and fresh	Viscosity	API Code RP13B Marsh Funnel	>40 s @68F	Twice per shift
Final Specifications				
Backfill at Trench	Slump	ASTM C143	3-6 inches	Twice per shift
Backfill	Unit weight or mud balance	API Std 13b	15 pcf greater than slurry	Twice per shift
Backfill	Permeability	ASTM D 5084	$1x10^{-7}$ cm/sec. Different conductivity may be appropriate at some sites.	One sample per 400cy or other appropriate volume
Backfill (typically only for CB)	Compressive Strength	ASTM D 5102 7-day unconfined strength test.	70 psi for structural or per design specification	One sample per 400cy or other appropriate volume
Key into impermeable layer	Visual Confirmation of boring.	On site borehole confirmation that impermeable layer is being keyed into.	At least 2 ft tie in.	Every one hundred foot during installation.
Monitoring Well/ Piezometer Network	Biweekly sampling until compliance attained then quarterly moving to annually.		1 ft head differential across the wall. Lower differential may be appropriate at some sites.	MW installed every 400 ft.

6.0 Operation and Maintenance (O/M):

6.1 Maintenance Plan Submittal:

A plan for operation, maintenance, and monitoring should be submitted for review and approval for all sites proposing engineering controls, including slurry walls. The plan may be submitted as part of a work plan (i.e., corrective action plan, remediation work plan) or as a stand-alone document. This plan or portions of this plan can be referenced in a statutory enforcement document to serve as a primary mechanism for long term management of the slurry wall. An example O/M plan is included as Appendix 1.

Acceptable Inspection and Maintenance Guidelines:

Materials	Design Life (Typical)	Inspection Frequency	Inspection Criteria	Maintenance Actions
Slurry Wall CAP	CAP Lifetime	As Scheduled (spring)	Pooling/ Puddles/ Discoloration	Fill depression/ Resurface / Regrade
			Erosion: Swales/ Gullies / Ripples	Fill depression/ Resurface / Regrade
Pumping System	System lifetime	Monthly inspection.		
Slurry Wall	Wall Lifetime	Annual	Ensure wall is protected from breach by root penetration, degradation from traffic loading and cracking from desiccation.	Remove vegetation and eliminate traffic.
Monitoring Well/ Piezometer Network	Biweekly sampling until compliance attained then quarterly moving to annually.		1 ft head differential across the wall. Lower differential may be appropriate at some sites.	MW installed every 400 ft.

7.0 References:

American Petroleum Institute; 2003; API Recommended Practice for Field Testing Water-based Drilling Fluids 13B-1 Third Edition, December 2003 ANSI/API 13B-1/ISO 10414-1

EPA; 1984; Slurry Trench Construction for Pollution Migration Control EPA-540-84-001

Indiana Department of Environmental Management, “Remediation Closure Guide”, Non Rule Policy Document Waste-0046-R1, https://www.in.gov/idem/resources/nonrule-policies/effective-nonrule-policies/, July 9, 2012.

Ryan, C. and Spaulding, C; 2007; Vertical Groundwater Barriers for Contaminated site reclamation. Presented at the, “Proceedings of the 10th Australia New Zealand Conference on Geo-Mechanics, “Common Ground”, Brisbane, Australia; Available at http://www.geo-solutions.com/resources/vertical-groundwater-barriers/

Ryan, C, PE; Day, S.; Soil Bentonite Slurry Wall Specifications. Geo Solutions White Paper available at: http://www.geo-solutions.com/resources/soil-bentonite-slurry-wall-specifications/

Appendix 1:

EXAMPLE SLURRY WALL OPERATION AND MAINTENANCE PLAN

[DATE]

Property Located at:

[ACTIVITY ADDRESS]

[City, County]

[IDEM Program Area and Program ID]

Introduction

Instructions: This document is an example 'Operation and Maintenance Plan' for a slurry wall at the above-referenced property. Edit the template appropriately in the bracketed areas.

This Operation and Maintenance Plan has been prepared by [*insert name of preparer*] for the slurry wall remedy installed at the above-referenced site. It outlines the policies and procedures for the long-term maintenance and monitoring of the slurry wall on-site. The onsite contaminated [soil] [and/or] [groundwater plume] is impacted by [enter list of contaminant(s)]. The location of the slurry wall and accompanying pumping system and monitoring well network to be maintained in accordance with this plan, as well as the impacted [soil] [and] [groundwater plume] are identified in the attached map.

Cover Purpose

The slurry wall serves as a barrier to capture, contain, or divert groundwater contamination. Based on the current and future use of the property, the slurry wall should serve these functions unless disturbed or deteriorated.

Inspection/Monitoring Activities

The slurry wall as depicted in the map may be inspected [*insert proposed time frame* (annually, semi-annually, quarterly, etc.)] [in the months of [April or May] [insert other timeframe]]. The inspections may be performed to ensure that the slurry wall remains intact, settling is not occurring and that the wall is protected from breach by root penetration, degradation from traffic loading and cracking from desiccation. Any accompanying groundwater capture system may be inspected [*insert proposed time frame* (annually, semi-annually, quarterly, etc.)] [in the months of [April or May] [insert other timeframe]] to ensure that the system is functioning properly and that well vaults and pumps are operational. The monitoring well network may be inspected [*insert proposed time frame* (annually, semi-annually, quarterly, etc.)] [in the months of [April or May] [insert other timeframe]] to ensure that the monitoring well network is maintained; this inspection should be coordinated with the agreed upon sampling periods necessary to ensure that the agreed upon head differential is maintained across the wall. A log of the inspections and any repairs should be maintained by the property owner. The log may include recommendations for necessary repairs. Once repairs are completed, they may be documented in the inspection log. The inspection log should be kept on site and made immediately available for review by the IDEM Office of Land Quality (OLQ), its successor, and/or other appropriate state agency.

Maintenance Activities

If problems are noted during the annual inspections or at any other time during the year, repairs may be scheduled as soon as practical. In the event that necessary maintenance activities expose underlying contaminated soil or groundwater, the owner should inform maintenance workers of the exposure hazard and provide them with appropriate personal protection equipment ("PPE"). The owner should also sample any soil or groundwater that is removed from the site prior to disposal to ascertain if contamination remains. The soil or groundwater should be treated, stored and disposed of by the owner in accordance with applicable local, state and federal law.

The property owner, in order to maintain the integrity of the slurry wall system, may maintain a copy of this Maintenance Plan on-site and make it available to all interested parties (i.e. on-site employees, contractors, future property owners, etc.) for viewing.

Amendment or Withdrawal of Maintenance Plan

This Maintenance Plan can be amended or withdrawn by the property owner and its successors with the written approval of the IDEM Office of Land Quality.

Contact information for person/persons responsible for implementing this plan.

[NAME]
[ADDRESS]
[PHONE #]

Site Owner and Operator:

[NAME]
[ADDRESS]
[PHONE #]

OLQ: [OLQ Program Area]
[ADDRESS]
[PHONE #]

Inspection / Maintenance Activity Log: The following table should be used to track and monitor maintenance activity to ensure that remedial objectives continue to be met in the future. This table can be included in the proposed remedial action plan (or equivalent document).

Inspection Date	Inspector	Inspection Criteria	Maintenance Action Needed	Previous Maintenance Completed?