Soil-Bentonite Slurry Wall Specifications
Especificaciones para Muros Colados de Suelo-Bentonita

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Abstract

Specifications for the construction of Soil-Bentonite slurry walls have been developing for over 30 years. In this paper, the elements of good specifications and recommended parameters are discussed. Recent new provisions in specifications and their potential contributions to the cost and/or quality of the finished product are evaluated. Examples include requirements for low slurry sand content, undisturbed backfill sampling, cleaning the backfill, and other recent additions to "standard" specifications. Recommendations are made as to the best methods for field sampling of the slurry trench backfill and testing for permeability in the field and laboratory.

Resumen

Las especificaciones para la construcción de muros colados de suelo-bentonita han estado desarrollándose por más de 30 años. En este artículo se discuten los elementos que hacen buenas especificaciones y los parámetros recomendados. Se evalúan nuevas cláusulas recientemente introducidas en especificaciones y su contribución potencial al costo y/o calidad del producto final. Los ejemplos incluyen requisitos para bajo contenido de arena en el lodo bentonítico, toma de muestras inalteradas del relleno, limpieza del relleno y otras adiciones recientes a las especificaciones "estándar". Se recomiendan los mejores métodos para la toma en campo de muestras del relleno de la trinchera y ensayos de permeabilidad en el campo y el laboratorio.

1 INTRODUCTION

The technique of slurry wall construction has become more commonplace on geotechnical projects. It remains, however, a method that requires the skills and onsite expertise of experienced slurry specialists. Thousands of slurry walls have been installed since the early 1970's. The vast majority of these installations have been soil-bentonite (SB) slurry walls. At its most basic level, this technique involves digging a long slot under bentonite slurry and backfilling it with a blended mixture of the excavated soil, dry bentonite and bentonite slurry to form a relatively impervious barrier. Usually the trenches are dug with a hydraulic excavator and the backfill is mixed on the ground next to the trench with earthmoving equipment.

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 a knowledgeable slurry specialist, 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.

In some cases, more detailed specifications have improved construction methods. In other cases, new kinds of specifications add only to the cost of the work without improving overall quality and sometimes actually have been a detriment to the final product or have created unfortunate conflicts.

In this paper, the authors discuss the typically specified slurry wall parameters and some implications of different kinds of specifications for each of them. The recommendations in this paper are specific to the construction of SB slurry walls and may not apply to other types of slurry walls.

2 SLURRY PARAMETERS

2.1 Slurry Test Methods

The test methods that are used in the slurry construction process have been derived from the oil well drilling industry and were originally specified by the American Petroleum Institute in their Standard Procedure for Field Testing Drilling Fluids (API RP13B). There now are corresponding ASTM specs for most of the same tests. The standard tests used for slurry work include:

- Viscosity-Marsh Funnel
- Unit weight-Mud Balance
- Filter press
- Sand content

These tests are all relatively simple for a slurry specialist to run in the field and are generally all that are necessary to control slurry properties.

There is another viscosity test that is occasionally included in slurry wall specs, the rotational (or direct-indicating) viscosimeter. This instrument is more complex than is needed for field purposes and there is little practical field experience working with it on slurry wall projects, although it can be useful for laboratory studies. It is, however, generally unsuitable for production work in the field.

2.2 Freshly Mixed Slurry Properties

The test that is most useful to determine initial (freshly mixed) slurry properties is the Marsh Funnel (MF) test. The results of this test are related to bentonite content, the type of bentonite used and the degree of hydration. If there are impurities in the mix water that interfere with the hydration of the bentonite, this test will usually give the slurry specialist an indicator of that problem. While a ”40 second MF” slurry is typical of an initial bentonite slurry, variations from this value, both up and down, should be allowed to adjust the in-trench slurry as necessary. Water quality and bentonite quality have a major effect on slurry properties and may require the use of a slurry with a different viscosity.

The specific gravity or density of the slurry as freshly mixed is often specified, but this is not particularly useful. Because of the high efficiency of bentonite and job-to-job differences in bentonite and water quality, slight differences in density can make large differences in viscosity. The difference in performance of a slurry with a specific gravity of 1.03 vs. 1.04 can be very large, and the typical mud balance used to measure specific gravity has a resolution of only 0.01. Often, specifications will have minimum values of specific gravity that are impractical to attain with the specified bentonite. For example, a specific gravity (often seen in specifications) of 1.05 will usually result in a slurry that is too thick when standard bentonite is mixed with good quality water.

For the same reason, it is not good practice to specify the minimum bentonite content of slurry. Minimum values of 5% are often specified and can result in slurry that is too thick, depending on water and bentonite quality. Most slurry mixing equipment is not capable of proportioning by weight anyway. Contractors constantly adjust volumetric mix ratios to achieve viscosities appropriate for their circumstances.

The filter press test is a test that is much over-specified in slurry wall work. The test is designed to measure water loss of a slurry under a pressure of 690 kPa (100 psi) and the thickness of the resulting filter cake. It has particular value to the oil well industry where boreholes are very deep and a thicker filter cake can prevent the return of drilling fluid. In an excavated trench, a thicker filter cake is not a problem and may actually improve the overall quality of the wall. Since a lower filtrate is also related to hydration of the slurry and proper mixing of the slurry, it is really a test that should concern the contractor more as an economic issue; lower filtrate values should result in lower slurry losses through the trench walls.

It is appropriate to say a few words about Wyoming-type bentonite clays. There are essentially three kinds of bentonite that are marketed for slurry wall applications. The most common is “standard” 90 barrel yield bentonite as specified in API Publication 13A, Section 4. The second is “untreated” or “natural” bentonite as specified in API Publication 13A, Section 5. And the third is “chemically resistant” bentonite that is specially formulated by the bentonite manufacturers and is sold under various trade names. There are other types of materials, including “high yield” bentonites (e.g. 180 barrel yield) that are never used in these applications because they result in too little clay in the final product. Occasionally, a severe chemical environment will mandate the use of alternative materials such as attapulgite or a chemically resistant bentonite, but this is rare.

After conducting hundreds of bentonite design mix studies, the authors conclude that the only bentonite-related factor of real importance in the final permeability of the wall is the bentonite content, by weight. Even in cases of chemical contamination, the so-called “chemically resistant” bentonites seldom show a performance improvement for this application. There is also usually no practical difference in performance between the standard bentonite and the “natural” bentonite. The authors prefer standard bentonite because it produces more reliable slurry properties. Because of the cost differential between these products, the authors strongly recommend first trying the standard bentonite in all design mix programs and specifying this material if design mixes produce acceptable results.

Specifications will often require a minimum bentonite content in the backfill, generally expressed as a percentage of bentonite added to the backfill by dry weight. Unless otherwise specified, this is taken to mean all the bentonite that is added to the backfill, whether in the form of slurry or in the form of additional dry bentonite added at the time of backfill blending. This type of specification inevitably leads to confusion because there is no way to measure the slurry component in the field; some gets mixed in as the trench is excavated, and some is added at various times to produce the desired consistency. The authors strongly recommend the use of the term "additional dry bentonite" in project specifications; it should be made clear that slurry added to the backfill at any time is excluded from this calculation. Of course, mix designs conducted in the laboratory should use the same convention. Typical ranges of dry bentonite may be from 0-3%, and sometimes higher as dictated by design specifications. Experience has shown that the bentonite contribution from the addition of the slurry is usually in the range of 0.5 to 1.5% added by dry weight.

It is also appropriate to include some comments on the quality of the water used to mix the slurry. Acceptable slurry can generally be made from most water sources, but any suspect water should be subjected to testing in a design mix program. Waters with high calcium content (hardness > 250 ppm) may require the use of soda ash or other pre-treatment. Specifications often list a maximum hardness of 50 ppm, which may be difficult to find even from potable sources, and unnecessarily restrictive. Excessively turbid water or water with high magnesium content or a low pH can also be problematic and should be avoided. Recycled water (sewage effluent) and industrial plant water have been used on some projects, but often create their own special challenges. If non-potable water is planned for a project, it should be used during the design mix stage too.

Another parameter that is frequently specified is hydration time (typically 8 or 24 hours) for the mixed bentonite slurry. Complete hydration is generally defined as the point when the slurry has reached a stable filter loss and viscosity. With some types of mix plants, hours of hydration may be necessary. In others, the slurry is essentially completely hydrated when it leaves the plant after a few minutes of mixing. In fact, this topic is one that would be better left out of specifications entirely. If a contractor uses poorly hydrated slurry, he will have problems controlling the slurry properties in the trench, but none of the consequences are detrimental to the project. In fact, as discussed in the section on filter press tests, it could be argued that the use of poorly hydrated slurry will result in thicker filter cakes and increased bentonite consumption, all positive in terms of final wall permeability.

2.3 In-Trench Slurry Properties

Controlling the in-trench slurry properties is the heart of the slurry wall operation. Many specifications prescribe a fixed interval, such as twice daily, when all the standard in-trench slurry tests should be made and set forth parameters that the tests must meet for specification compliance. In practice, the knowledgeable slurry specialist will instead test the slurry many times per day, at different locations, using a limited number of tests, (primarily viscosity), to determine what is happening in the trench and what modifications are needed. Most specifications do not recognize the amount of variability that is typically encountered in the field.

The tests that are specified for in-trench slurry are typically the same as for freshly mixed slurry. Once again, the most important parameter to control is viscosity. Slurry specialists may use a thicker viscosity in situations where trenching is proceeding through highly pervious materials or where it is desired to increase slurry weight by suspending more sand and fines. In other cases, the slurry may need to be thinned as it loses water into the sidewalls or thickens for other reasons.

The specific gravity or density of the in-trench slurry is monitored using the mud balance. As trenching proceeds, the slurry picks up weight due to entrained materials. Additional weight helps trench stability; however, if the slurry gets too heavy or too viscous, then the backfill will have more difficulty displacing the slurry as it is placed. Usually, the specific gravity is required to be a minimum of 1.10 to 1.40 to maintain trench stability, depending on the soil type. Typical specifications also require that the slurry have a specific gravity no heavier than 0.25 (15 pcf) less than that of the backfill. For a backfill with a specific gravity of 2.0 (125 pcf), this computes to a maximum slurry specific gravity of about 1.75 (109 pcf). Some specifications set an additional upper limit as low as 1.36 (85 pcf). This may be unrealistic in sandy soils and too low to maintain trench stability in many cases. In general, the authors recommend keeping the slurry specific gravity at least 0.25 less than the backfill, thereby avoiding the pitfalls of over-specifying.

A related factor is sand content. The sand content of slurry is dependent on the viscosity of the slurry, the material through which the trench is being dug (and becomes suspended in the slurry) and the methods employed by the slurry contractor. Typical values for a trench being dug in sandy soil may be as high as 30% without impacting the quality of the installation. Some recent specifications have included maximum limits on sand content in the range of 10-15%. Mathematically, it can be shown that 15% sand content limits the specific gravity to about 1.26 (79 pcf), which can be much less than necessary to maintain trench wall stability. In the opinion of the authors, such arbitrarily low limits are counter-productive and invariably increase costs and controversy. On a relatively fast moving slurry wall project in a sandy soil, this provision will slow production considerably and usually for no discernable purpose. The use of large desanding machines is often not practical and almost never effective, as the only efficient (i.e. timely and practical) means to reduce sand content is to remove old slurry and replace it with fresh slurry. In the authors' experience, there is really no effective way to desand slurry on an SB slurry wall site without drastically increasing construction costs and reducing productivity. The effect of working with desanders for a long time or exchanging and wasting large quantities of slurry will quickly be reversed as soon as trenching starts again. In the authors' opinion, rather than trying to specify this controversial parameter, it is preferable to monitor and deal with any sedimentation during the trenching operation.

The last test often applied to in-trench slurry is the filter press test. The results from this test are heavily influenced by sand content for the in-trench slurry and have no value from an operational or quality standpoint. It is sometimes assumed that low filtrate losses produce improved trench wall stability. However, in practice, trenches have been maintained stable with very high filtrate values. In the case of cement-bentonite slurry walls, for example, filtrate values of 100-200 cc's are common. The authors recommend deleting this test from specifications for in-trench slurry.

3 SOIL-BENTONITE BACKFILL

3.1 Mixing and Placing SB Backfill

SB backfill is usually mixed and placed with earthmoving equipment such as bulldozers and excavators. The typical specification will require that the backfill is mixed "until homogeneous and a slump of 7 to 16 cm is measured". The slump cone (ASTM D143) is a simple test; after it is performed a few times, a trained operator and slurry specialist can usually begin to assess the proper slump by visual observation. It is more difficult to determine what the term "homogeneous" means for a given project. The mixed SB is usually allowed to contain occasional clods of clay and rocks up to a certain size. All particles should be coated with bentonite slurry and large particles (> 10 to 15 cm) should be removed or segregated. On projects with very hard clay, the tracks of a bulldozer can be useful in reducing clod size. When large rocks are encountered, the excavator can segregate the oversize materials (although the occasional cobble is not detrimental to wall quality). The authors have found that the ideal equipment spread uses a bulldozer paired with a small track-mounted excavator for optimum production and quality in mixing and placement of the SB backfill material.

Occasionally, specifications require the use of a pugmill to mix backfill. In the authors' experience, this equipment is not well suited for SB slurry walls because it relies on a constant flow of feedstock material and the materials excavated from slurry walls are poorly suited (wet and sticky) for conveying in and out of the mill and tend to create a highly variable end product. Pugmills have a very short mixing cycle and it is easy to get inconsistent results, unless the feedstock is pre-mixed or relatively homogeneous before mixing. Frequent on-off cycling of the pugmill can lead to additional inconsistencies as the beginning and end of the process again tend to be different blends. Pugmills can also entrain air into the SB, creating longer backfill slopes and making placement under slurry more difficult. With the traditional methods of mixing with bulldozers and excavators, the mixing process can continue as long as necessary for any batch of material.

The most important aspect of the backfill blending process is to mix backfill that complies with parameters set by the specifications for the proportions of key components. An engineer may set these requirements based on experience or they may be developed during the course of a design mix program. Most design mixes will focus on the allowable gradation range for the blended backfill, particularly the fines content, and the required amount of bentonite added to the blend.

Most soils found at a site can be used in backfill blends or, at the worst, can be amended slightly to meet a target gradation. SB backfill needs a fines content of least 15-20% (preferably but not necessarily plastic fines) to be stable under most circumstances. At the coarse end, it makes little sense to add gravel to a blend that does not naturally have gravel.

Contaminated soils can be used successfully in SB backfill. Contaminated sites are generally subjected to a design mix study and the contaminated soil should be used as the base material in the study. In most cases, there is little detrimental effect of contaminants and what there is can be counteracted by slight increases in bentonite content.

Dry bentonite is added in the field at the point of mixing. Typically a certain weight of bentonite is added to a known volume of backfill. This may be accomplished by setting the bentonite bags along the trench at distances proportional to depths or by adding known weights of bentonite to bucket counts of backfill blend in a remote mixing area.

Sometimes the slurry specialist will vary the slump of the backfill to improve workability. For example, the slump may be made stiffer (to reduce the length of open trench) if the work platform is steeper than normal, or if the aquaclude on the bottom of the trench has a steep dip. The slurry specialist may increase the slump to improve the flow of the backfill around a corner.

Some specifications require a dike of soil beside the trench to limit unmixed particles of soil from dropping into the trench during backfill mixing. The authors recommend cleaning the top of the trench with the excavator (about 1 bucket wide on each side) of all loose materials. This provides a "clean zone" that is more effective at preventing accidentally dropped materials, allows visual inspection of the top of the trench for cracks, and is much easier to monitor.

3.2 Field Sampling of SB Backfill

Testing of the SB backfill requires a sampling method to obtain test specimens. Usually, "grab samples" are obtained by the slurry specialist from the mixed materials on the work platform, immediately prior to placement in the trench. These samples are placed in sealed plastic bags and sent to the laboratory for testing. A typical sampling interval is one sample for laboratory testing per 400-1000 m^3 of backfill, which is about one test per one to three days of normal production.

Some specifications require "undisturbed" samples of the backfill at depth. This method has the advantage of obtaining in situ samples, but has several potential drawbacks. First, since the SB is placed in at a wet consistency, some period of consolidation and "setting" time is normally necessary prior to sampling. The time delay can be unacceptable for quality control and final acceptance on a typical project. Second, unconsolidated SB is difficult material to sample since the material is soft, wet, and may contain stones. Shelby tubes are recommended and piston sampling tools are sometimes required for adequate recovery. It may not be possible for backfill materials containing gravel particles to be sampled "undisturbed". Third, most drilling & sampling methods have a relatively poor record for maintaining verticality. This problem is exacerbated when the sampling is performed in a deep and narrow trench, where the exact center of the trench may be poorly located. This can result in the sampling tool recovering the trench wall instead of the SB backfill. For example, at about 10 m deep, a drill stem 3% out of vertical can exit a 1 m wide trench, if the drilling begins in the middle of the trench. Finally, the trench may be constructed nominally vertical (some specifications require within 3%), but local soil variations, boulders, etc., can cause the trench to deviate. For these reasons, in situ sampling is limited by practical concerns to about 10 to 15 m in depth, and even then may require repeated efforts to obtain representative samples. In situ sampling, when employed, is usually performed at 120 to 150 m horizontal intervals.

The authors recommend not relying on in situ sampling for final wall acceptance. The conventional method of obtaining a grab-sample that is reconstituted in the laboratory is a more reliable and timely test.

3.3 Laboratory Testing of SB Backfill

Samples of SB from slurry wall construction are usually sent to a laboratory for testing. The tests typically performed are grain size and permeability (or hydraulic conductivity) and less often, Atterberg Limits. With respect to grain size, the fines content (percent finer than 0.075 mm or #200 sieve) is the property of interest. Adequate fines content (at least 15-20%)

generally results in an acceptable permeability and a backfill with greater resistance to piping. A well-graded material is highly recommended but specific requirements for intermediate sieves (e.g. #4, #40, #100, etc.) usually result in unnecessary complications or the wholesale rejecting of otherwise usable site soils with no improvement in quality. Reuse of the site soils is highly recommended if at all possible for simplicity as well as economy.

Experience has shown that high fines content soils (clays) can be used as backfill; it is not necessary to add gravels to predominately clay mixtures to flatten their grain size curve and reduce fines. The only limitation in using clayey soils is that a longer period of consolidation may be required prior to final capping when these soils are used as backfill

Permeability is the most commonly specified performance parameter for SB walls. Triaxial (or flexible wall) tests, as per ASTM D5084, are the industry standard test. On most projects, samples of the backfill are gathered from the mixing operation, just prior to placement in the trench for testing. Laboratory permeability testing of SB samples can be challenging since SB samples are semi-fluid and require some type of preparation prior to mounting on a test pedestal. Some laboratories tamp the SB into a temporary tube placed inside the sample membrane and then induce consolidation prior to testing. Others form a test specimen by consolidating the SB in a cell with a sliding piston. By pressurizing the cell, the SB is pre-consolidated and a “cookie” of SB is created that is more easily handled and tested.

Consolidation pressures and the testing gradient must be specified for the triaxial test. Some specifications require effective confining pressures as low as 40 kPa; the authors recommend 50 to 100 kPa. As for gradients, the lower the gradient, the less additional consolidation of the sample will undergo during the test, but more time is required. Gradients of 10 to 30 are typically used for these tests. The wrong combination of a confining pressure and gradient can create problems for the laboratory and the potential for failing the specimen.

Specifications sometimes include a requirement (or option) for on site permeability testing of the SB using a modified filter press. This test, known as the filter press perm, quick perm, or Q-test can be used to get a relatively rapid indication of SB permeability for field quality control purposes. Use of the Q-test requires a low-pressure regulator (0-200 kPa) and a correlation (and correction factor) with the laboratory triaxial tests. Most slurry specialists can run this test and obtain reasonable results overnight. Usually, one laboratory triaxial test is required for every 5 Q-tests.

3.4 In Situ Testing of SB Slurry Walls

Engineers are always looking for ways to test the permeability of a slurry wall in place. No test has yet been developed to accomplish this goal.

Methods that involve inserting some kind of pumping element into the wall and then pumping in or out are not likely to provide reliable results. Pumping out will most likely cause a hydraulic fracture of the wall and bad results. Pumping in only works as a rising head test because of the low permeabilities involved; interpreting data is difficult and the results can be heavily influenced by a well being off center in the wall.

Pumping from one side of the completed wall and looking for drawdown on the other side will only find the grossest flaws and then only if the wells are fortuitously located near the flaw.

The only method shown to have reliably assessed the bulk transmissivity of a slurry wall is to create a substantial test cell and then do a pumping test. Unfortunately, these tests are very time consuming and expensive and not justifiable for the typical project. Trying to economize by making a very small test cell will result in using techniques not typical of a longer wall and, therefore, not be a good model.

4 CONSTRUCTION CONSIDERATIONS

4.1 Key at the bottom of the Trench

Most standard slurry wall specifications contain a clause related to the key required at the bottom of the slurry wall, typically 0.7 to 1 m (two or three feet) into an underlying aquaclude. Clearly the key is one of the most important aspects of the design of any slurry wall, yet engineers using standard specifications frequently do not address it on a site-specific basis.

In cases where the key material at the bottom is of low quality, a deeper key may be necessary. Where the key at the bottom is very hard or variable as it would be in the case of a weathered rock, a 1 m (three foot) key may be more than necessary and may be very expensive to attain. Aggressive efforts to make a key may actually damage the rock beneath the key and create flow paths that could short-circuit the barrier. The authors recommend specifying a key to a design minimum depth, or to the refusal of the excavating equipment, whichever is less.

4.2 Keying Between Sections

Almost every project involves keying the excavation of a SB wall into a previously backfilled section, usually to close a loop around a site, although there may be other reasons to join sections together.

The standard way of doing this when the new and old segments cross at some angle is to dig through the crossing point by some amount on both the old and new segment. The "overlap" distance is typically specified at a minimum of 1.5 m (5 ft.) With standard survey control, overlaps longer than this are excessive and wasteful.

When the old and new segments are on the same line, the same procedure can be followed, digging out approximately 1.5 m of the old wall measured at the bottom. Alternate procedures of trying to lap wall segments by digging alongside the old wall are not recommended because slight deviations in verticality can result in a soil window being left at the bottom.

4.3 Cleaning Of the Trench Bottom

The specification provision that typically causes the most controversy on SB slurry wall sites is the one related to cleaning of the trench bottom. The concern is that, during some period of inactivity on the site, sand will settle out of the slurry and cause the deposition of a pervious zone that will subsequently be covered by backfill. Specifications typically require that the depth of the bottom of the trench and the surface of the backfill be measured at ten or twenty foot horizontal intervals after excavation is completed for the day and before it starts in the morning. The intent is to measure if excessive sand has been deposited during the work stoppage. In most cases, the amount of sand that sediments out is minimal and usually less than can be measured.

Good technique involves bringing the toe of the backfill up close to the excavated face after the completion of the day's excavation work. The following morning, the bottom of the trench can be cleaned completely by the excavator and a portion of the previous day's backfill dug out of the toe. The theory is that the new backfill will scour any sedimentation off the previous face or mix it to the point where it is not a problem. Of course, any sedimented material is completely surrounded by bentonite slurry and this also would tend to diminish any effects of the sedimentation.

The problem is that there is no effective way to clean the portion of the backfill that is out of the reach of the excavator. For trenches that may be as deep as 50 feet or more, the excavator can typically reach only the very bottom of the slope that may be hundreds of feet long. Specifications often mention acceptable means of cleaning of the trench bottom as using clamshells, airlifts, pumps or similar equipment. All of these methods have practical limitations and may cause more problems than they solve. On many sites, there is simply no room beside the open trench to accommodate the lifting equipment to operate any of these devices. The excavated spoil may be on one side of the trench, waiting to be blended and landfill slopes, structures, or other features frequently constrict the other side. Even when there is access for lifting equipment, using a clamshell is a clumsy operation that certainly destroys filter cake and risks knocking more material from the sides of the trench onto the backfill surface. Airlifts and pumps at best can suck a hole in the surface of the backfill. They cannot clean even a small part of the surface because they cannot be moved laterally in viscous slurry. If they are picked out of the slurry and moved, they will still miss parts of the backfill surface. Furthermore, since the backfill surface is sloped, the length of the suction line must constantly be changed, impeding the progress of the work. The authors have witnessed attempts to drag a small bucket or sled down the backfill slope with the idea of scraping off any accumulated sand. It is impossible to control this device as it comes down a backfill face hundreds of feet long dragged by cables that increasingly apply lifting forces as the bucket-sled approaches the bottom.

The bottom line on cleaning the trench bottom is that there is no effective way to do it beyond the reach of the excavating equipment. The time spent attempting cleaning would be far better spent in production so as to increase the distance between all the potential faces. Specifications that require cleaning of the backfill face after eight hours of work stoppage always result in controversy at the site, sometimes followed by ineffective measures taken just to satisfy an engineer or a standard specification with no practical improvement in quality.

Occasionally, real sedimentation is measured at the bottom of the trench or up on the backfill slope. This may be caused by small trench collapses, breakdowns in the slurry quality, or excessive time with the trench left open. In these cases, the contractor effectively only has two choices. One is to walk the excavator out over the trench (preferably on crane mats) to the point where the trench can be cleaned. The second choice is to simply continue backfilling and come back at a later date to re-excavate the affected area or otherwise re-mix it. (Deep soil mixing and jet grouting have been used to make these kinds of repairs.)

Other than these situations, a small amount of sedimentation is always going on, even during excavation and backfilling and is just a part of the process. The authors hesitate to suggest a standard for what is too much sedimentation. What is normal in one situation might not be in another. Certainly typical sedimentation is less than 15 cm (6 inches) on a trench of 15 m (50 foot) depth.

4.4 Measuring Trench Width

Trench width is normally assured by specifying that the excavating bucket have a minimum width equal to the desired trench width. While it is possible to measure trench width directly with mechanical callipers or a sonar-like device, these types of measurements are costly, time consuming and generally not advised. For most slurry wall applications, if there is some decrease of the trench width by squeezing, it will show at the surface in the form of cracks and a narrowed trench

4.5 Capping and Consolidation of Slurry Walls

A completed slurry wall must be capped to protect it from desiccation, traffic, and root growth. Since the SB material is very soft when placed, a cap of substantial material also protects the public and limits (or even eliminates) future maintenance.

The SB material is very wet when placed and therefore subject to consolidation. However, with the narrow trench widths usually constructed for slurry walls, the backfill tends to adhere to the trench walls and resist substantial settlement. Experience has shown that most of the consolidation for SB slurry walls is over in about 2 weeks (for 1 m wide walls, less for thinner, more for thicker walls). A good specification will require the contractor load the top of the slurry wall with excess materials (excess backfill, trench spoil, etc.) to a height of 0.5 to 1.0 m. This load prevents desiccation prior to placement of the final cap, and helps accelerate settlement. After a period from a few days up to two weeks, the load is removed and the slurry wall can be permanently capped. On larger projects, capping is phased with other slurry wall operations so that capping follows excavation and backfilling with minimal delay.

5 CONCLUSIONS

When writing specifications for SB slurry walls, engineers need to be cognizant of the impact of key specification sections on the construction process. There are many specification provisions that can have severe consequences on the constructibility and cost of slurry wall projects. Specifications should account for specific site conditions and project needs of the site in question and not be simply copied from other projects.

REFERENCES

American Petroleum Institute (1990), *"Recommended Practice Standard Procedures for Field Testing Water-Based Drilling Fluids"*, Specification RP 13B-1, Washington, DC.

American Society for Testing and Materials (2000), <u>*Annual Book of ASTM Standards*</u>, Section 4: Construction, Vols. 4.02 and 4.09, West Conshohocken, PA.

Geo-Solutions Inc. (2003) *"Standard Soil-Bentonite Slurry Wall Specification"* www.geo-solutions.com

Millet, et al (1992), *"USA Practice Slurry Wall Specifications 10 Years Later,"* <u>Slurry Walls: Design, Construction, and Quality Control</u>, ASTM STP 1129, Paul, Davidson and Cavalli, Eds., American Society for Testing and Materials, Philadelphia.

Millet and Perez (1981), *"Current USA Practice: Slurry Wall Specifications"* Journal of Geotechnical Engineering Division ASCE Vol. 107 No. GT8.