Cement-bentonite slurry typically consists of water, Ordinary Portland Cement (OPC), cement replacement materials such as Ground Granulated Blast furnace Slag (GGBS) or Pulverized Fuel Ash (PFA) and sodium-enriched bentonite, as well as various admixtures and retarding agents. The slurry is batched on site and injected into a trench where it cures to form the low permeability barrier. The main utilization of this barrier is to retard the flow of groundwater, thus curtailing the mass of contaminant that is transported away from the site via the movement of water. Such migration is known as advection and is the dominant transport process for normal conditions. Contaminants may also migrate via diffusion; this process is based upon the random movements of the contaminant, driven via concentration gradients, and tends to be far slower than advection in normal conditions. However, in low permeability conditions diffusion can be an important method of transport. When barriers are used to form a containing structure, some form of pumping system
is usually employed in order to lower the pressure head of the groundwater on the inside of the wall. This will create an hydraulic gradient across the wall that acts into the site, thus reducing the risk of advective migration away from the site (i.e. due to a change in differential water level by an external influence). There is however the possibility of a concentration gradient developing across the wall, inducing diffusive fluxes away from the site (Refer Figure 1). Refer Figure 2 for cement bentonite slurry stabilized slope.

One key Use of this Cement Bentonite Slurry System could be in Construction of deep open foundations where the existing water table is very high. The application could be in form of trenching across the perimeter of the excavated foundation and filling the cement bentonite slurry system in the trenches which on curing creates an impermeable wall for water and aides smooth underground construction. Also it can be used in pitching of the side slopes of canals where soil stabilization problem is there because of higher ground water table and causes frequent collapse of the slope.

Basics

A bentonite grout consisting of just bentonite and water may not be volumetrically stable and introduces uncertainty about locally introduced pore water pressures caused by the hydration process. Introducing cement, even a small amount, reduces the expansive properties of the bentonite component once the cement-bentonite grout takes an initial set. The strength of the set grout can be designed to be similar to the surrounding ground by controlling the cement content and adjusting the mix proportions. Controlling the compressibility (modulus) and the permeability is not so easy. Weaker cementitious grouts tend to remain much stiffer than normally consolidated clays of similar strengths. The bentonite solids content has the greatest influence on the permeability of cement-bentonite grout, not the cement content. Cement-bentonite grouts are easier to use than bentonite grouts, provide a long working time before set and are more forgiving should the user deviate from the design recipe or mixing equipment and method. It is easier to adjust the grout mix for variations in temperature, pH and cleanliness of the water. Pure bentonite grouts must be mixed and deployed by strictly following measured quantities and procedures that are not common practice among drillers doing test borings.

Performance Requirements and Properties of Cement Bentonite Slurry Systems:

The long term ability of Cement Bentonite (CB) Slurry system to perform as effective hydraulic containment barriers and the ease with which they can be constructed is strongly influenced by the properties of the slurry that forms them. The properties are:

Density

Density should be sufficient to provide the necessary hydrostatic force required for the structural stability. The slurry density required to achieve this will depend on the nature of the surrounding ground. Researcher’s found that although the initial density of CB slurry ranges from 1040 kg/m3 to 1150 kg/m3, it usually rises to around 1250 kg/m3 by the end of excavation. For self-hardening slurries in-trench density of 1300 kg/m3 is generally thought to be the threshold level above which workability is impaired.

Bleed

Low bleed characteristics are desirable since excessive loss of water constitutes a loss of useful slurry volume and indicates that the slurry mix is unstable. Although maximum bleed levels of 2% are often specified, JEFFERIS (1981) states that bleed of less than 1% can be achieved by a well designed CB slurry mix.

Rheological Properties

The rheological properties of CB slurry are extremely important in determining bleed characteristics, filter loss, setting times and ease of construction. The slurry needs to be thick enough to support the solid material within it and be fluid enough to facilitate excavation of the trench. Parameters that are used to indicate the capacity of a slurry mix to fulfill these criteria include viscosity, gel strength and thixotropy. Thixotropy is the property of hydrated bentonite to set to a gel-like consistency but to return to a fluid state upon agitation. This is extremely
useful for maintaining solid material in suspension during periods when agitation from construction activities has ceased. The thixotropic behaviour of bentonite is the main reason for its inclusion in CB slurries.

Setting Time

The setting time required depends on the method of excavation and the depth of the cut-off wall. Setting time should always be adequate to facilitate continuity of day joints. Setting times in excess of 36 hours may be required to ensure that slurry remains workable after weekend or bank holiday periods (PRIVETT et al., 1996). In addition to affecting construction, setting time will determine the amount of excavation spoil that gets trapped permanently within the wall (JEFFERIS, 1981). Longer setting times allow more spoil to settle out of the slurry and consequently promote the development of better barriers. Setting time is extended by Ground Granulated Blastfurnace Slag (GGBS) replacement since GGBS has lower hydraulic activity than OPC. Barriers containing GGBS are generally excavated slightly deeper into impermeable strata to allow for the accumulation of spoil near their bases.

Filter Loss

During barrier construction slurry is lost to the surrounding ground. Initially, hydrated bentonite particles begin to occupy pore spaces between soil grains. The degree of penetration and hence the volume of slurry lost depends on the porosity of the ground. Eventually enough bentonite particles accumulate to form a tightly packed low permeability seal called a filter cake (XANTHAKOS, 1979). The filter cake has the dual purpose of reducing further slurry loss from the trench and providing a skin of semi-solid material on which the hydrostatic pressure of the slurry can act. The latter is important for trench stability.

Permeability

Permeability is the most important parameter for cut-off walls. Regulations concerning the containment of waste and contaminated ground are becoming increasingly stringent and permeabilities below 10⁻⁹ m/s are often required. The specification of permeability is complicated by the fact that for CB slurry, permeability is dependent on a number of external factors. All research indicates that permeability reduces with increasing curing time, time of permeation and confining pressure. An increase in the solids content and in particular the bentonite content of CB slurry will also lead to a reduction in permeability (MANASSERO et al., 1995). Sodium bentonite produces lower permeability slurry than calcium bentonite and the partial replacement of cement with GGBS reduces permeability by 1 to 2 orders of magnitude.

Slurry walls require sufficient strength to withstand the forces exerted on them. Such forces include self-weight, lateral earth pressures from soil and nearby structures and hydrostatic pressures from differential groundwater levels (MEGGYES and PYE, 1995). Since the magnitude and distribution of forces is difficult to assess, the material strength required is not usually known. In an attempt to overcome this problem, a minimum strain at failure of 5% was once commonly specified. However, since strain at failure is influenced by external factors, an unqualified value such as this is of little real significance.

Laboratory Testing

- Specification for the basic slurry mix, as used at Pride Park, Derby (BARKER et al. 1998)

- SAMPLE PREPARATION - Bentonite and water (90% by weight of bentonite) were mixed in a mechanical mixer for 30 minutes. Fixed mixing period was employed in order to standardise the mixing time as the properties of CB slurry are highly dependent on it (JEFFERIS, 1981). After mixing, the bentonite/water slurry was left to stand overnight to hydrate. Jefferis (unpublished) states that this is important for proper hydration of montmorillonite particles, and thus for the reduction of bleed.

Mix Design Rules

In order to keep field procedures simple the emphasis should be on controlling the water-cement ratio. This is accomplished by mixing the cement with the water first. This is contrary to procedures used at more sophisticated

<table>
<thead>
<tr>
<th>Property</th>
<th>Requirement</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bleed</td>
<td>&lt; % (after 24 hours)</td>
<td>Measuring cylinder</td>
</tr>
<tr>
<td>Density</td>
<td>1119 kg/m³ (±10 kg/m³)</td>
<td>Mud balance</td>
</tr>
<tr>
<td>Viscosity</td>
<td>-</td>
<td>Marsh funnel</td>
</tr>
<tr>
<td>Permeability</td>
<td>&lt; 1x10⁻⁸ m/s at 28 days</td>
<td>Triaxial cell</td>
</tr>
<tr>
<td>Strain at failure</td>
<td>&gt; 3% at 90 days (at an effective confining pressure of &gt; 120 kpa)</td>
<td>Drained triaxial compression</td>
</tr>
<tr>
<td>Undrained shear strength</td>
<td>&gt; 25 kpa at 14 days</td>
<td>Undrained triaxial compression</td>
</tr>
<tr>
<td>Unconfined compressive strength</td>
<td>&gt; 150 kpa at 90 days</td>
<td>Unconfined compression</td>
</tr>
</tbody>
</table>

Figure 2: Circulation batch mixing of grout (minimum configuration)
grout plants for compaction grouting and sealing purposes. When water and cement are mixed first, the water-cement ratio stays fixed and the strength/modulus of the set grout is more predictable. If bentonite slurry is mixed first, the water-cement ratio cannot be controlled because the addition of cement must stop when the slurry thickens to a consistency that is still pumpable.

Mixing Procedure

A rig pump with one suction hose and a return hose fitted with a jet nozzle and a 50-gallon barrel, shown in Figure 2, are the minimum requirements for circulation batch mixing of grout. Paddle or high shear mixers can also be used. Amended quantity of clean water goes into the mixing tub/barrel first and the pumping and circulation starts.

Then the cement is gradually added to the water and mixed thoroughly. At this stage the mix is like gray water. Next, bentonite powder is slowly added into the jetting area of the barrel, slowly enough so clumps of bentonite do not form. This should be constantly checked by scraping the bottom with a shovel. When clumps form, slow down and do not add any more powder until they are dissolved. Keep adding bentonite until the mixture transitions to an oily or slimy consistency. Observe the consistency while mixing and let the grout thicken for another five to ten minutes. Generally, the mix thickens some more with additional mixing time. Add more bentonite powder if required. When it is smooth and like thick cream or pancake batter, it is as heavy as it is feasible to pump. Drips of the grout should then barely come off a dipped finger and should form “craters” in the fluid surface. That is the correct consistency for pumping the groutbatch down the tremie-pipe. When possible, withdraw the tremie after each batch an amount corresponding to the height level in the boring to keep the pumping pressures as low as possible. When mixing grout 100 feet or more from the borehole, thinner consistency would be required, but at the risk of some bleeding.

Conclusion

It can be concluded that the ability of a particular CB slurry mix to achieve design requirements almost exclusively depends on the nature and relative proportions of its constituent materials. Designers are often forced to specify mixes that are only capable of achieving a specified permeability to the detriment of overall performance. Typically, bentonite contents are increased and cement contents correspondingly reduced. This inevitably leads to losses in strength and setting ability, in addition to the desired reduction in permeability. Developments in the use of cement replacement materials have to some extent overcome this problem. Indeed, the partial replacement of cement with ground granulated blast furnace slag (GGBS) or Pulverised Fuel Ash (PFA) is known to have a beneficial effect on strength, setting ability and permeability. Unfortunately, the addition of GGBS to CB slurry reduces strain to failure and thus compromises the ability of the material to withstand deformations without cracking. Research work is needed to carry out to see the impact on use of other industrial mineral by-products like rice husk ash, silica fume etc. along with cement to the bentonite slurry.

Reference

- ACD Royal, Investigating the Hydraulic and Diffusive Properties of Cement-Bentonite Low Permeability Barriers.
- JEFFERIS S.A., Cutoff Walls. Notes from a short course on contaminated land, Queen Mary and Westfield College.