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Recommended Citation

R. V. Sarsby, "Control of uplift from ground water" (June 1, 1988). International Conference on Case Histories in Geotechnical Engineering. Paper 5.
http://scholarsmine.mst.edu/icchge/2icchge/2icchge-session1/5
Control of Uplift from Ground Water

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SYNOPSIS: This paper relates to the conversion of a disused water reservoir into a landfill site for domestic and industrial refuse. The reservoir was initially subdivided into four cells (by using earth bunds) and three of the cells have been successfully prepared and filled. The fourth cell is the largest and presents the greatest number of geotechnical problems, the major one being the problem of ensuring that leachate does not escape into the groundwater.

The first owner of the site removed natural clay from various parts of the reservoir base to seal the first three cells. In doing so he exposed water-bearing sandstones, mudstones and badly-shattered shales and ground water is now issuing freely from these strata. Standpipes in the base of the completed cells indicate a significant artesian pressure in the groundwater and sealing of the exposed rocks in cell 4 represents a major problem. In an attempt to form a low permeability seal with compacted clay temporary pressure relief drains have been installed to connect with the water bearing rocks. However closure of these drains may lead to excessive uplift pressure and rupture of the seal and so the relief drains will be left open, whilst waste is placed, until they can be safely closed.

THE SITE

The site is a disused water reservoir which is being converted into a disposal area for domestic and industrial refuse - a general plan of the location is shown in figure 1. The reservoir lies in a natural valley with the ground falling generally from North to South. When the reservoir was no longer required it was drained and the dam, which consists of a puddle clay core with boulder clay shoulders, was breached.

Although there are no records of the construction of the reservoir a deep well (at position W) to supplement the natural inflow into the catchment. During the boring of this hole the observed ground stratigraphy was 4.5ft (1.37m) of soil and clay overlying water-bearing bands of fissured shale, sandstone and gritstone. A limited hand auger survey in the basin of the site confirmed that the ground profile consisted of a relatively-thin layer of clay overlying water bearing shattered shale and fissured sandstone. The thickness of the clay varied from 2.5 ft (0.76m) in the bottom of the valley to 12.8 ft (3.9m) at the edges. Both the ground level and the underlying rocks rise from South to North and to the North of the site the fissured sandstone forms the bed of the stream which fed the reservoir. The foothills of the Pennines are approximately 2 miles (3.2km) North of the site. The auger holes revealed an artesian pressure in the shale and sandstone and groundwater issues were visible at several locations in cell 4.
To develop the site for refuse disposal the local authority required that the basin of the reservoir should be sealed by the establishment of either an impermeable membrane or a low permeability clay liner. The clay liner has to have a minimum thickness of 1m and a permeability of not greater than 10⁻⁷ cm/sec. Falling head permeability tests showed that for certain areas of the site the naturally-occurring clay had a sufficiently-low permeability to act as a partial sealing layer. In addition compaction permeameter tests confirmed that clay was available on site which could be compacted to achieve the requisite permeability. The first owner of the site opted to install a clay liner for two reasons:

1) There was sufficient, suitable clay on site - in fact in some parts there was a naturally-occurring partial clay liner.

2) The clay liner option was very much cheaper than installing an impermeable membrane which would itself have to be contained within low-permeability clay layers.

INITIAL SITE DEVELOPMENT

The initial development of the site was undertaken by a person who had no experience of waste management or earthworks and as described in an earlier paper (Sarsby 1987) his first attempts at forming a clay liner had resulted in much good quality clay being contaminated and wasted. Cells 1 to 3 were eventually lined and filled with waste but in the process the problems associated with cell 4 (by far the largest cell) were greatly exacerbated. The problems were:

1) Partial loss of naturally occurring clay seal. To line cell 3, and to form containment bunds, clay was removed indiscriminantly from cell 4's basin so that the thickness of the natural clay seal varied randomly over the site and in many places its thickness was reduced well below the necessary one metre. In addition earthmoving had taken place wherever the weather and the wheels of the plant had created deep ruts which had penetrated through the clay, thus creating leakage points.

2) Exposure of underlying water-bearing strata. The underlying shales and sandstone had been uncovered and groundwater issues created (as indicated in figure 2) due to removal of clay for use in cell 3 and due to 'rutting' and 'bogging-down' of earth moving plant. These issues created large ponds and miniature stream courses at many locations within the basin of cell 4.

3) Clay could not be placed and compacted to the required degree where there was standing or running water. The natural moisture content of the in-situ clay was significantly greater than the optimum value and adding water and then kneading the soil (as in field compaction) rapidly causes the clay to degenerate to mud - as discovered by the site developer. The North-West of England has a damp climate which severely restricts the times when earthworks can be undertaken. Even during the drier parts of the year the numerous ground issues meant that there was always a lot of standing water on the site.

4) The development of high uplift pressure from the groundwater. Extrapolation of the pumping data from well W indicated that the steady-state water level in the borehole would be close to the ground surface - the top of the well being approximately 12m above the lowest point of cell 4. A standpipe had been installed to measure the development of head in the shales underlying cell 3. When this cell was sealed the water level in the standpipe rose to 2.8 ft (0.86m) above the lowest part of the clay seal, i.e. 6.8 ft. (2.07m) above original ground level. This head rise had occurred despite the fact that issues 1), 2) and 3) were acting as pressure relief points. With cell 4 sealed it was estimated that the underlying head could rise to 8m above ground level. If there was insufficient weight on top of the seal at this stage then uplift and consequential fracture of the liner would occur.

5) There appeared to be insufficient clay on site for the completion of the liner in cell 4. Importation of material would be very costly since there was no suitable source in the immediate vicinity and the use of an impermeable liner would be even more costly (even if such a liner were only used over part of the area). Even if an impermeable membrane were used then sealing clay would need to be placed above and below it as a 'fail-safe' measure against puncture of the membrane.

TREATMENT OF CELL 4

Availability of clay

The first thing to be done was to identify the zones where there was already an adequate natural liner (low permeability clay not less than 1m thick) and the zones where additional clay was required - as shown in figure 2. This investigation was undertaken by hand auger. "Undisturbed" samples of clay were taken using a 4" (102mm) diameter cutter driven into the ground to obtain a plug of soil approximately 4½" (114mm) long which was then subjected to a falling head permeability test. All of the samples tested had permeabilities in the range 0.10 to 0.60 x 10⁻⁷ cm/sec, so that this material should satisfy the local authority requirements for...
sealing clay. Furthermore it was estimated that the volume of suitable clay was just sufficient for the completion of a 1m thick sealing blanket over the whole cell and the construction of a clay core within the dam breach. This balancing of volumes would only apply if; (a) clay could be excavated from one part of the cell and then be compacted elsewhere, to achieve a maximum permeability of $10^{-7}$ cm/sec, and; (b) there was no further wastage of suitable clay material.

**Compaction/Permeability Control**

Random samples were taken from the 'borrow' areas of the site and were subjected to compaction and permeability tests to provide both a specification for placement of the clay and a rapid means of checking that the liner would have the requisite permeability.

Dry density/moisture content relationships were established in accordance with the procedures contained in BS 1377 (1976). For each sample relationships were derived for both standard compaction (Proctor) and heavy compaction (modified A.A.S.H.O. test). The resultant compact curves are shown in figure 3. For each type of test the six soil samples gave very similar compaction curves. The effect of increased compactive effort is to increase the maximum dry density and reduce the optimum moisture content. However on the 'wet side' of optimum there is close correspondence between the data obtained from the two types of test. The natural moisture content of the clay ranged from 13.5 to 17.6%, i.e. wet of optimum and in the region where both standard and heavy compaction gave virtually identical dry unit weight values.

Since the compaction curves for the samples were very similar it was decided to establish the variation of permeability with compaction state for only one clay (sample 1) using both standard and heavy compaction. For the other samples the coefficient and permeability was only determined for optimum and natural moisture content under both standard and heavy compaction. The permeability was determined using permeameters into which the clay was compacted, at a specific moisture content, in accordance with the requirements of BS 1377. To saturate the samples gentle vacuuming was employed so that water was drawn up through a specimen.

The results from the permeability test programme, which are presented in figure 4, agree with the trends reported by Daniel (1984). The data show several important points:

1) On the 'dry side of optimum' the coefficient of permeability ($k$) increases rapidly as moisture content and dry unit weight decrease.

2) Minimum permeability is obtained when the clay is compacted slightly 'wet of optimum'.

3) On the 'wet side of optimum' the permeability is virtually independent of moisture content (at preparation) or dry unit weight.

4) Increased compactive effort decreases the permeability - in this case by a
Permeability factor of approximately 3 in going from standard to heavy compaction.

v) Clay compacted at natural moisture content had a permeability less than $10^{-7}$ cm/sec.

As a consequence of the preceding findings it was agreed with the Local Authorities that quality control of the liner (as regards permeability) would be undertaken by monitoring the dry density and moisture content of the compacted clay. To be acceptable the material would have to be wet of Proctor optimum and have a dry unit weight not less than that obtained from standard compaction at that moisture content. In addition samples of the compacted clay would be taken for permeability testing (as each part of the cell was prepared).

Groundwater control

To be able to place the clay liner satisfactorily standing and running water had to be eliminated from the cell. The easiest way to do this would be to collect the groundwater within relief drains, discharge the water from site and compact the clay liner over the drains. However the Local Authorities will not accept permanent underdrainage to a refuse site in case the liner leaks and hence pollutes groundwater and stream courses. Unfortunately any relief drains could not be closed immediately after preparation of the liner as the induced uplift from the ground water would fracture the clay seal - the clay was only 1m thick and the anticipated uplift head was about 9m maximum. To overcome these problems the following method of operation was proposed:

i) Connect all issues to relief drains and lead these to a central collection point (the freshwater chamber). Water is then discharged from this point to a stream to the South of the site.

ii) Complete the clay liner while the groundwater is being discharged freely.

iii) Test the integrity/impermeability of the liner by applying an excess head to the groundwater, i.e. raise the level of the outlet from the relief drains. The head to be applied (0.5m above ground level) is insufficient to lift the liner and has to be maintained for a minimum of 28 days. If leaks develop in the liner these should be eliminated (with the excess head removed) and then the whole liner should be re-tested for 28 days and so on until no leakage occurs.

iv) Commence reinstatement of the breached dam so that the fill in the breach is at least 3m above the floor level of cell 4.

v) When the liner has passed the pressure test install leachate drains and commence construction of the leachate chimney.

vi) Place waste in the cell and simultaneously raise the level of the outlet in the freshwater chamber so that the groundwater head is always 0.5m above the surface of the refuse. Check the purity of the water in the chamber and if it is clean discharge it into the stream to the South of the site.

vii) Once the level of water in the outlet pipe becomes static, i.e. there is no further overflow of groundwater, close the relief drains off and seal the freshwater chamber. The cell can then be completed in the usual manner.

The proposal was accepted by the authorities for several reasons:

a) It enables the whole of the clay liner to be pressure tested for leaks and imperfections.

b) The groundwater pressure is controlled so that it never exceeds the overburden thus preventing lift and fracture of the liner.

c) The groundwater pressure will always be greater than the pressure in the leachate inside the cell (due to regular pumping from the leachate chimney) so that there will be no tendency for leachate to flow out of the cell if the liner becomes porous.

d) During filling of the cell the purity of the groundwater is checked so contamination would be quickly detected.

e) If the groundwater does ever become polluted then the problem can be contained by opening the outlet pipe in the freshwater chamber. This chamber will consist of a permanent manhole built into the dam just downstream of the central clay core. If the outlet pipe is opened at its lowest level, i.e. the bottom of the manhole, and the
chamber is pumped out then groundwater will flow to the chamber since it is the lowest point in the system. Thus polluted water would be drawn to the outlet from whence it would be taken for treatment.

WORK UNDERTAKEN

Figures 5 and 6 show general views of cell 4 after completion of clay lining. In figure 5 the original dam is in the right-hand-side of the picture. The breach is approximately half-way along the embankment and has a shallow bund in front of it so that reinstatement of the dam can be commenced. The upstream slope of the dam is currently 1 on 2½ but this will be cut back to 1 on 2 to provide fill for the breach. Figures 5 and 6 show the proximity of the site to residential properties. The view in figure 6 was taken from the South-East corner of the dam with the bund between cell 3 and 4 being on the right-hand-side of the picture. The water in the basin of cell 4 is not from ground water issues but is due to rainfall (Manchester and the North-West being a notoriously damp part of England).

Data from tests on the compacted clay of the liner are presented in figure 7. The earthworks were undertaken using an 'end-result specification', i.e. acceptability of the work is based on the end result rather than on strict adherence with a specified method of working. Quality control was undertaken by specifying that the clay should be compacted in accordance with the relevant Department of Transport specification (1976) as regards weight of compaction plant, number of passes of the roller, etc. Quality assurance was achieved by checking that the compacted clay had the appropriate moisture content and density values (as stated previously) together with a limited number of permeability tests and pressure testing of the completed liner. After placement all of the material was well wet of Proctor optimum with dry unit weight values close to the theoretical curve for 100% saturation - the compacted clay was generally denser than the laboratory samples formed using either standard or heavy compaction. The permeability of the field specimens is in keeping with the laboratory data obtained for heavy compaction and is well below the requisite $10^{-7}$ cm/sec. These data vindicated the method used for the quality assurance/control of the clay liner.

To collect all of the ground water issues 3 major relieve drains had to be installed. At the location of each weep a perforated section of pipe was inserted into the line and was covered with a granular filter. Clay was then compacted by hand around the drains before they were covered by the full clay liner. The pipes were brought to a common junction in the basin of the cell from where the single 4 ins (102 mm dia)
The left-hand picture shows the drain emerging from a protective steel pipe under the temporary access across the breach. The other view shows the outflow from the relief drain which at this stage was approximately 0.6 litres/second (about 480 gallons/hour). When the outlet was first raised and the liner was pressure tested a few leaks were detected—indicated by the bubbles in figure 10. At these locations the liner was dug out completely and carefully recompacted. For the past six weeks the clay has been under pressure and no further leaks have been detected. Work is now starting on the sealing and reinstatement of the dam breach, and it is anticipated that tipping of refuse will commence in about four weeks—during the whole of this time the liner will be left under test.

CONCLUSIONS

A method of forming a clay liner (for a landfill site) has been devised to overcome uplift induced by groundwater issues at a particular site. The method has two major benefits: the integrity of the completed liner is checked and leakage of leachate from the landfill is inhibited by the positive groundwater pressure which will act on the exterior of the liner once the site is filled. Control of the placement of the clay liner (to achieve the requisite low permeability) was undertaken by a simple specification based on bulk unit weight and moisture content as a result of the data obtained from an extensive laboratory programme of permeability testing.

REFERENCES