

Leak location surveys - geophysical testing of geomembranes used in landfills

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1.0 Introduction

Geomembranes are required as an element in multi-layer composite basal lining systems for landfill sites. They are installed over a mineral based liner of either compacted clay soil and/or a geosynthetic clay liner (comprising two geotextiles with a bentonite clay sandwiched between them). Installing a geomembrane requires particular care to ensure the liner provides a continuous seal across the entire site. They are thin and can be occasionally damaged even when laid by careful competent installers. CQA inspectors visually inspect and record the liner as it is laid and welded and the seams are tested and repairs made, but damage often occurs later during placement of the protection and drainage layers.

Geophysical testing provides an effective means of confirming a geomembrane is forming a complete seal beneath a body of waste after all these phases of construction are complete. It is often required as part of the CQA Plan. Planning and carrying out the survey needs to be considered from the outset to ensure it is effective. As part of the validation process, it is necessary to provide the results from a geophysical testing identifying the location of the extent of the testing, any damage caused during construction and that any damage has been repaired and re-tested.

There is no requirement to carry out such surveys on geomembrane capping systems.

Essentially, there are two main geophysical test systems currently in use,

- mobile surveying and
- fixed test systems.

Mobile testing provides a one-off test after construction is complete and identifies any damage whilst a fixed system can provide information over the life span of the system which is typically a number of years.

This document explains the theory behind the present geophysical surveys available and how they are implemented. We hope it will provide landfill operators with the knowledge they need to appreciate the technology and terminology used. You can find guidance on other aspects of geomembranes in the Industry Code of Practice "Using geomembranes in landfill engineering".

There is a common expectation that these surveys should detect all holes regardless of their size, this is not the case. Outlined within this document are some the limitations of the technique and problems of detectability, many of which can be addressed by careful planning, preparation and timing.

Geophysical testing doesn't replace traditional construction quality assurance (CQA) techniques, but rather provides the ability to test the whole liner after the construction phase. A geophysical survey will not for example, provide information on the quality of materials used or the strength of welds. A survey will (if undertaken correctly) show that no leaks of greater dimension than the sensitivity of the survey exist. Regulators, consultants and operators must consider the CQA system as a whole, balanced against the risk to the environment of a leak of a certain size being present.

The detail in this document supports the UK government's general approach to landfill engineering which is detailed in the Environment Agency's Landfill Sector Guidance.

2.0 Background

Until the early 1990s, construction quality assurance (CQA) procedures were based

mainly on visual assessment methods, testing welds and on taking spot samples from the body of the liner. A shortcoming of geomembrane CQA techniques is that they do not indicate damage to the membrane that may occur during the placing of the overlying materials. Geophysical testing methods provide a means of testing a membrane after a cover has been placed.

There are now several modified geomembrane materials which are designed to enhance the electrical properties to aid this form of testing although there is little experience of the use of these in the UK.

The advent of geophysical systems in the USA and Europe has enabled the testing of large areas of membrane after the placing of the protective layer and drainage media. This type of testing extends the ability of quality assurance engineers to confirm the integrity of a geomembrane. Many geophysical methods could be applied to liner integrity such as, ground probing radar and microwave techniques. This document only details electrical resistivity systems, which have proved the most successful to date. In the US ASTM produce a standard guide on selecting techniques for potential leak paths in geomembranes using this technique (ASTM D 6747-04) which may be useful.

3.0 Mobile surveys

3.1 Mobile surveying - operating theory

The first mobile survey of a landfill in the UK was carried out in 1993. Mobile surveying takes place after a liner has been laid and the protective cover materials (generally a protective geotextile and drainage media) have been installed. A mobile survey is a one-off test to ensure a liner has not been damaged during installation or the placing of the cover materials.

The system operates by exploiting the insulating properties of polymeric geomembranes. To ensure no electrical leakage occurs, a strip of geomembrane should be left exposed around the perimeter of the test area to ensure complete electrical isolation from the underlying mineral liner and/or adjoining phases or cells.

An electrical voltage is passed between two power electrodes, a fixed electrode placed in the ground outside the lined area and one placed in the cover material within the cell. A moveable pair of measuring electrodes is then moved around the cell in a grid pattern measuring the electrical potential within the liner. During a survey, as the moving electrodes approaches a defect along a particular grid line, the electrical potential increases gradually. As the electrode passes the defect, the polarity of the signal reverses and then gradually decreases as the electrode moves away from the defect. See Figure 1.

The electrical potential data collected from the portable monitoring electrodes is then processed and plotted. Where leaks in the geomembrane exist, characteristic signals are produced allowing accurate location, repair and re-tested of the affected places.

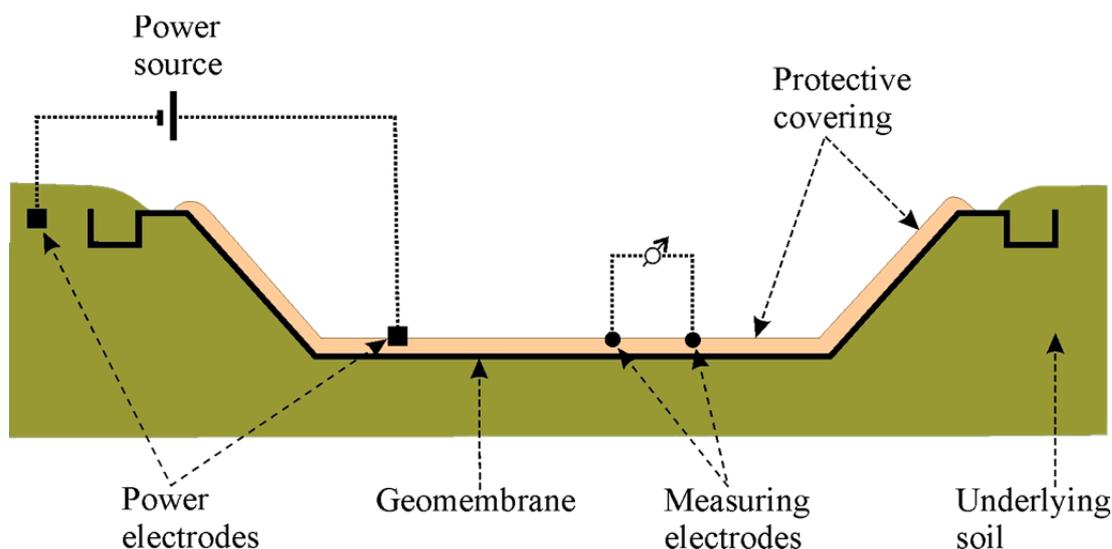


Figure 1 Typical Walk-over Survey

3.2 Mobile surveying - system capability

Assuming that the site is well electrically isolated, the sensitivity of geophysical surveys, that is, the ability to detect a hole of a given size depends on a number of variables. These include the magnitude of the applied voltage, the thickness of the cover material, the spacing of the grid and the conductivity of the materials above and below the liner. The electrical sources used vary from 12 volts DC batteries to portable AC generators. The voltage is generally amplified to approximately 300 volts.

Smaller holes have lower cross-sectional areas and higher electrical resistances, therefore in order to achieve a detectable, measurable current, a higher voltage is needed. For a given hole size, the signal strength caused by the leak decreases as the soil thickness increases.

Experience has shown that for the system to operate successfully, the soil above and below the liner needs to be moist but not saturated and the natural moisture content of most soils is sufficient to conduct an electrical current. However, if the soil cover is too dry it may be necessary to wet it prior to carrying out a survey. A water bowser and/or spray guns can be used for this hydration and if there is any doubt about the suitability of the materials a test to demonstrate the suitability of the method being used must be carried out. Successful leak location surveys have been conducted over a range of coarse aggregate drainage layers.

The sensitivity of the method used should be assessed and it is recommended that the CQA engineers assess the sensitivity of the survey by one of the following methods:

i) Wire Test (Blind Leak)

Place the bare end of a coated copper wire in the ground outside the lined area with the other bare end to the surface of the geomembrane. This will deliver current inside the liner and demonstrate whether the equipment is functioning, and test its sensitivity. You must remove the wire once the pre-testing is complete.

ii) Test Hole (Actual Leak)

Deliberately making a hole in the geomembrane at a position unknown to the survey team to ensure that the system is functioning as specified. If you choose this method, make the hole well away from the sump area. Once you've made the hole, firm the geomembrane down against the subgrade to ensure no air void exists below the membrane, as any air void will prevent the electrical current from being transmitted. Replace the cover material

once you've made the test hole, then wet the cover soil to ensure it and any geotextile will be conductive. Whether or not the survey team detect it, the test hole must be repaired by experienced personnel and retested (in accordance with section 3.6) to ensure there are no leaks.

The further implication of this is that holes in wrinkles may not be detected by this method - giving greater importance to ensuring that the liner is in intimate contact with the subgrade. However, if the site conditions are good and the underside of the membrane wet, a hole on top of a wrinkle may be detectable.

Where a geotextile is used as a protective layer above a geomembrane and this extends across the uncovered zone around the periphery, it is possible the geotextile could bridge the insulation layer around the site and cause a fall-off in detectability.

Geocomposite drainage layers have large voids and high flow and unless they are saturated they act as isolators preventing the flow of current. Therefore slopes with these are virtually impossible to test and even bases may be difficult unless saturation is possible.

Specialists in this field recommend that ideally two walk-over surveys should be carried out, the first before any geotextile is placed on the geomembrane to find the location of very small nicks and holes, and a second after placing the protective geotextile and the drainage layers unless. These techniques differ slightly. In all projects there are practical and economic constraints and the need for rainfall/wetting to aid conductivity before both surveys as well as contractual delays and cost which usually mitigate against this strategy.

3.3 Mobile Surveying - Lagoon Surveys

Geophysical surveys have successfully also identified leaks in leachate lagoons at several sites in the UK. Lagoon surveys are very sensitive as water is an ideal conductor. In general, liquids are better than solids not because of their conductivity but because liquids can seep through tiny defects thus ensuring a good contact between media on top of the membrane and under the membrane. As with soil cover surveys, potential electrical leakage paths need to be eliminated by either removing or isolating the liner prior to conducting a lagoon survey.

At sites where there is a leak or suspected leak the level of liquid in the lagoon will need to be lowered and the base tested with a small level of water/liquid present allowing a walk-over survey. The slopes will then need to be surveyed using a suitable method for exposed membranes such as by using a water lance. This allows rapid repair and the re-survey of areas around repairs to be carried out more effectively.

3.4 Mobile surveying - preparing the site

- a) If the geomembrane is fully covered with a protective/drainage layer, an isolation strip, approximately one (plastic) shovel width around the perimeter of the survey area, should be exposed. In extreme circumstances surveys have been carried out without this strip, although this makes interpreting the data more difficult.
- b) Where the conductive medium/protective cover material is the same as below, say where

sand is used in a sand quarry, holes can be difficult to detect if not properly isolated. Detecting holes in this situation may involve changing the position of the inner and outer electrodes to ensure all holes have been detected. This affects both mobile and permanent systems.

- c) The cover materials should be examined to ensure they are sufficiently moist to allow current flow. In dry conditions, the measuring electrodes may need to be positioned just beneath the dry surface or the surface may need wetting using spray guns.
- d) Conducting materials (e.g. pumps, metal ladders, cables etc.) within the test area may affect the results; it is recommended that, where possible, all such materials should be removed.
- e) Isolate potential leak paths such as pipes.
- f) Mark the test area with numbered grid lines (using tape or rope), spacing between 0.5 and 2 metres is recommended.
- g) Place the electrodes, connected to a suitable power source in the underlying soils outside the test area.
- h) Occasionally it may be necessary to undertake testing over a geotextile protector but it is not recommended as damage may occur during placing of the cover or drainage layer. If this is necessary for site specific reasons, check that the geotextile is thoroughly wetted through to the geomembrane, and that the geotextile is in intimate contact with the geomembrane.

3.5 Mobile surveying - interpreting the data

Voltage readings between adjacent positions, usually 0.5 to 2 metres apart, together with the grid number and distance along grid lines, are collected and fed into an on-site computer either manually or via a data logger. However, greater spacing dramatically decreases the effectiveness of such a survey.

The computer generates graphs of voltage along grid lines generating a two dimensional plan view showing voltage contour lines. It is also possible to generate a three dimensional output. Examining the output may reveal anomalous readings, not all of which are caused by holes (for example, folds in the membrane, leachate drainage pipes and so on), an experienced operator should be capable of interpreting the data generated. Additional readings should then be taken to verify each anomaly and locate them precisely.

3.6 Mobile surveying - repairs and retests

Soil above a defect should be carefully removed ensuring no further damage occurs. Locate the defect, then mark and photograph it before having it repaired. Once completed carry out a retest of a ten metre radius around the defect to ensure that all leaks have been located and repaired successfully.

Ideally, the survey should be carried out while the lining contractor is still on site. This will enable speedy repairs and retests of the affected area without the additional costs of re-mobilising a survey team at a later date.

4.0 Fixed survey systems

4.1 Fixed systems - operating theory

Fixed Systems work on the same theory as mobile surveying, however a permanent array comprising a grid of wires and electrodes is installed beneath the geomembrane liner. They can detect liner defects prior to emplacing waste to prove 'built integrity', as do mobile systems, but also monitor operational integrity.

Fixed systems vary in their construction, the most common examples include a network of stainless steel electrodes buried in the soils beneath the liner, connected together by coated wire to a computerised monitoring station.

Fixed systems can detect the presence and extent of any leaks when they occur (in a lateral plane) which can be build up into a series of tomographs showing the distribution of voltage beneath the landfill over time. It is important to plot such tomographs prior to landfilling to allow subsequent routine monitoring to detect changes.

UK experience in about 17 sites indicates they are likely to provide monitoring over at least a period of years. These systems have been used in Europe and Asia but rarely in the USA, with the first such system used in the UK installed at a site in the Midlands in 1995. This is a preferable type of system to mobile surveying because it remains operational for an extended period of time and evidence from Europe has indicated that geomembranes can be punctured during their operational life due to the stresses and strains imposed by the waste body.

4.2 Fixed systems - system capability

Fixed systems provide a monitoring facility for a number of years. The service life of the installation will depend on the longevity of the materials. If for example wires corrode or couplings become detached during operation due to leachate attack after a leak the functionality of the system may be affected.

Fixed systems can be installed in localised high risk areas, such as those around landfill sumps or possibly up to the 1m leachate 'tide-line', and the extent of the installation should be based on the basis of a risk assessment. A restricted zone may be useful at sites where leachate control mechanisms are very efficient and it is not expected that leachate heads will rise above a specified head.

As with walk-over surveys, geocomposites on slopes can be difficult but once in operation the basal areas should remain saturated.

UK experience of fixed systems to date suggests they can be more sensitive than mobile surveys in relation to the hole size they can detect.

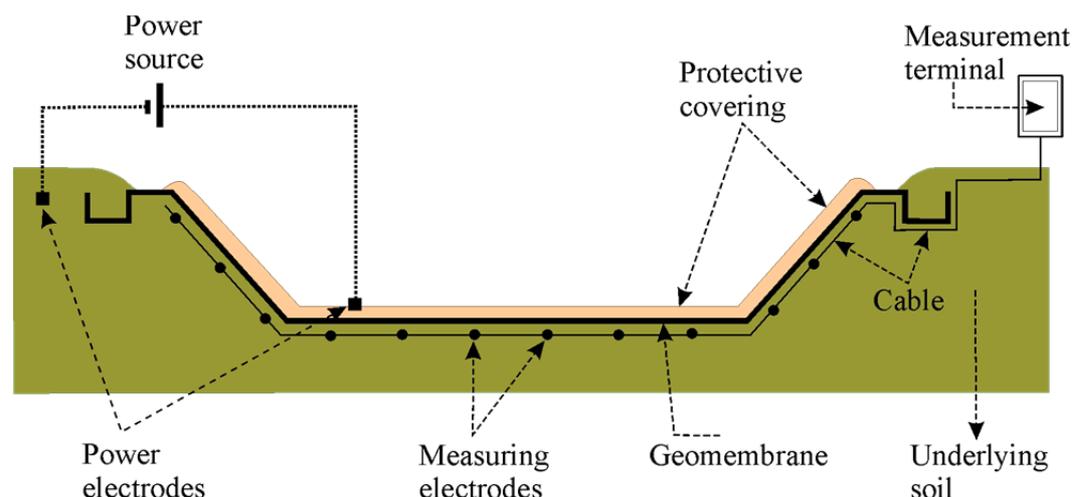


Figure 2 Typical Fixed System

4.3 Fixed systems - preparing the site

The site preparation for fixed systems will depend on the individual system being installed. A number of systems require you to excavate trenches and refill them, paying attention to the compaction of soils. There are so many potential issues that the each site needs to be considered individually and the contractor should provide a method statement to be agreed by all parties.

4.4 Fixed systems - interpreting the data

Data interpretation for fixed systems is similar to that for mobile surveys but there is the advantage of having a series of tomographs at regular intervals and changes can be deduced.

4.5 Fixed systems - repairs and retests

The system should be tested during installation to ensure all the connections are properly made. Once the liner is installed, carry out testing to detect any leaks and if any leaks are found mark and photograph them for record purposes, then arrange for them to be repaired. Once waste is placed it becomes ever more difficult to repair any faults.

4.6 Fixed systems - costs

Costs for fixed systems are significantly greater than those for mobile surveys, they also depend on the system you choose. The various system suppliers can provide more details on the likely costs involved.

5.0 Detectability of holes – requirements and limitations

For a successful leak location survey, the test area must meet certain technical requirements. The effectiveness of the electrical leak detection test depends not only on the ability of the leak detection service provider, but also on the design and on the site conditions.

At any site, the following criteria shall be met:

- Electrical conductivity (Conductive media must be present on both sides of the geomembrane, except for some walkover techniques used on bare membranes).
- Electrical isolation (Material inside the containment should be electrically isolated from the ground outside the containment).

5.1 Electrical conductivity

As the method works by mapping the artificially generated electrical field, it is clear that it only works in an electrically conductive environment. The electrically conductive media must be present on both sides of the geomembrane. At lined landfills, the conductive media may be water, leachate, soil (soil moisture), or a geosynthetic clay liner (GCL). Therefore, the electrical leak location system will not work effectively in the following cases:

- An extremely dry subgrade (e.g. crushed rock + geotextile in dry climate, dried out GCL).
- A dry intermediate monitoring layer in double liner systems (e.g. dry, washed gravel).
- No soil cover or liquid on the geomembrane (e.g. concrete slabs, slopes covered with dry geotextile or tyres).
- A frozen soil cover
- An extremely dry soil cover (dry weather conditions)

Even a relatively dry soil may contain enough moisture to conduct some electrical current. As more soil moisture is contained in fine grained soils rather than in coarse soils, a gravel layer containing fine particles is preferred to washed gravel or stone. If too dry, the site must be thoroughly wetted or the test must be postponed until a period of rain. Some period of time must be allowed for water to percolate down to the geomembrane. Problems with spraying the site are encountered if the soil cover has a low permeability, e.g. weathered slate, chalk, very fine sand, or a combined cover consisting of very fine sand overlain by a separating geotextile and gravel.

Furthermore, some conductive medium has not only to be present on both sides of the tested geomembrane, but must be in intimate contact with it, so that there is no other electrical insulator present except for the tested geomembrane. Some lining system components may act as such additional insulators:

- *A separating geotextile between two cover layers*
The textile may prevent the two layers establishing a good electrical contact with each other unless the site is thoroughly wetted. Here the use of the “mobile” system on the top of the upper layer is limited.
- *Geosynthetic drainage.*
There are various types of the geosynthetic drainage products available. Some create just a minor temporary obstacle for the leak location test (e.g. geonet coupled with a geotextile on one side), some are non-compatible unless fully saturated with water (e.g. a geocomposite consisting of a three-dimensional core sandwiched between the two textile layers), and some are completely incompatible with the “mobile” leak location system (e.g. cusped three-dimensional thermoformed plastic sheets).
- *Encapsulated bunds*, i.e. bunds built on the basal geomembrane and then lined with additional sheets of plastic. These structures may not be surveyed unless the test procedure is planned in advance.

5.2 Electrical Isolation (the degree of contact between the material inside the containment and the surrounding area.)

If the geomembrane is exposed around the perimeter of the tested area, it effectively separates two relatively conductive media – covering soil and surrounding earth. In such cases, the electric

current flows between the power electrodes via holes in the geomembrane. If the geomembrane is not exposed, or is only partly exposed, the proportion of current flow through holes is smaller in comparison with the current flow over the edges. Consequently, location of leaks becomes problematic.

6.0 Test holes

To assess the site conditions and also to test the performance of the service provider, test holes are sometimes made to the geomembrane before the leak location survey commences.

It must be remembered again that the electrical leak location test can only detect holes if the electrical current can pass through. It is a common misconception that if conductive media are present on both sides of the geomembrane, every hole is instantly detectable. Unfortunately this is rarely the case. A hole becomes detectable only if:

- it is large enough to enable a direct contact of the two conductive media on either side of the insulating membrane, or
- conductive fluid (soil moisture, water, leachate) is present within or is passing through the hole.

If enough time is allowed, some conductive fluid will eventually pass through every hole in the geomembrane, which means that, eventually, every hole becomes detectable. However, if there is a short time interval between making a hole and performing the leak location test, some holes may remain undetected. It is believed, that this happens more often with test holes than with “normal” holes as the test holes are often made just before the commencement of the test. Saturating the test hole assists in finding the test hole but may not be representative of the conditions of accidental holes over the remainder of the geomembrane in dry conditions.

Some examples of the temporarily undetectable test holes:

- *Tight cuts*

Small cuts are frequent geomembrane defects detected by the leak location tests under good site conditions. However, if a cut is made as a test hole, it may become undetected until some moisture starts seeping through. In dry weather conditions it may take a long time, especially when covered with a thick dry geotextile.

- *Small holes made on wrinkles.* When a hole is on a wrinkle, there is no electrical contact because of an air void between the geomembrane and the underlying media. With time, some electrical contact can be established when some liquid starts flowing through the hole, or when the bottom side of the geomembrane becomes wet due to moisture condensation.

- *“V” – shaped cuts*

This sort of hole is unlikely to occur as accidental geomembrane damage. However, it is quite a frequent way of making a test hole. When the “V” cut is lifted up and covered with a geotextile, an air void is created between the underlying and overlying soils and the hole remains undetectable for some time (see Figure 4a, 4b).

- *Other types of air voids*

These can also be created when geotextile is covering a small drilled hole, a small hole made by pushing a nail through the geomembrane (see Figure 4c), or a small hole made by pushing down and pulling out a tool like a screwdriver (see Figure 4d).

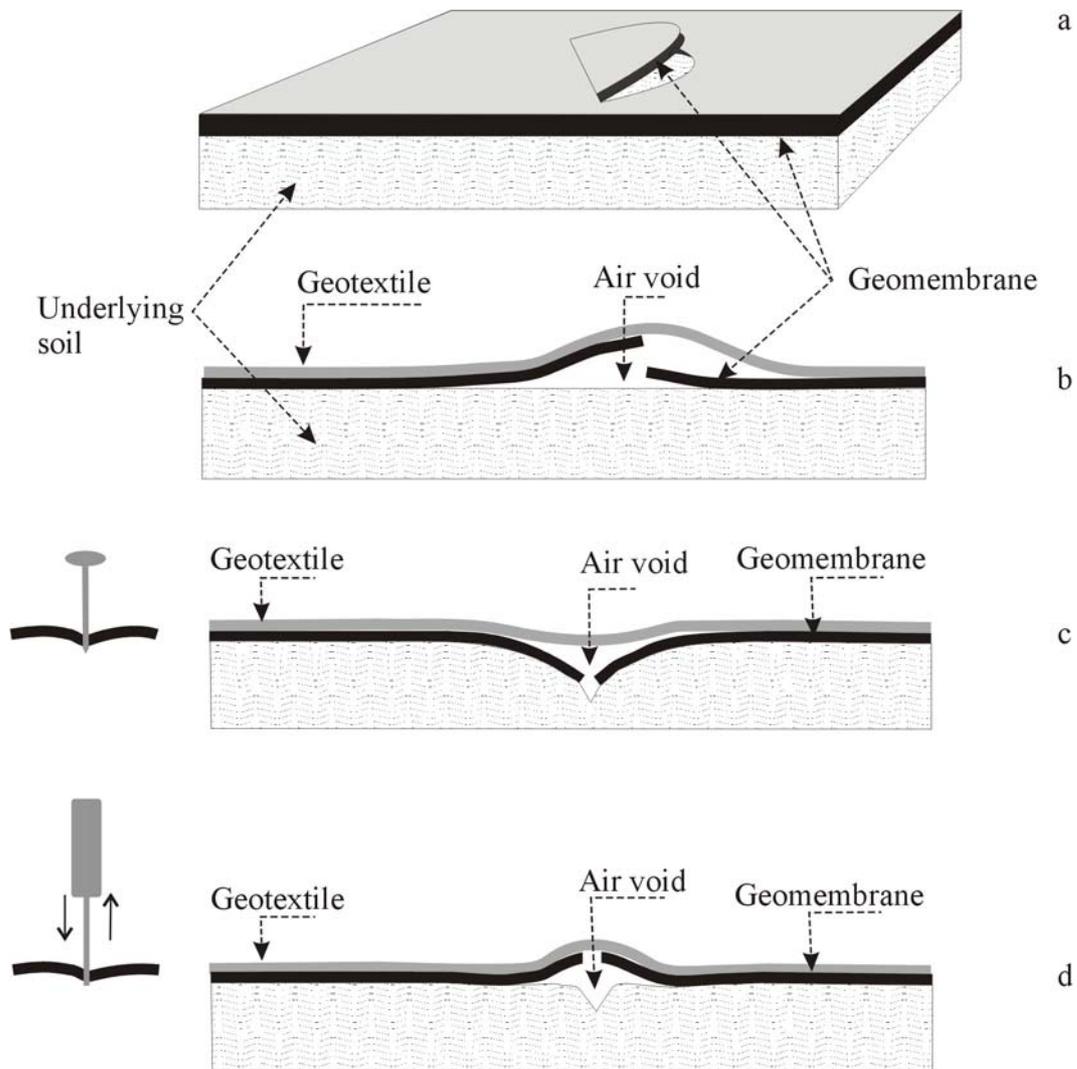


Figure 4. Some examples of test holes temporarily undetectable due to air voids.

Further reading

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Environment Agency technical sector guidance:

<https://www.gov.uk/government/collections/environmental-permitting-landfill-sector-technical-guidance>

Environmental Services Association (www.esauk.org) is in the process of setting up a page to host **Industry Codes of Practice for landfill**, such as this one