Infiltration rates for SuDS: Is it time to ditch BRE 365 tests?

Steve Wilson and Jacqueline Diaz-Nieto, EPG Ltd, discuss the alternatives to BRE 365 infiltration tests and whether testing is required when a desk-based study clearly shows infiltration will not be possible.

Introduction

Imagine a proposal for a new infiltration test method that comprises filling a deep pit, of roughly estimated dimensions, with water, taking no account of wall collapse and spalling during the test, analysing the results without consideration of soil stratigraphy in the pit, wasting resources such as water and gravel to fill pits, and being a method considered dangerous. It would not be considered acceptable, so why does the drainage industry and Lead Local Flood Authorities continue to think that BRE 365 infiltration tests are an acceptable approach when much safer and reliable methods of infiltration tests are available? These other test methods are also especially suitable for infiltration via sustainable drainage systems?

Recent articles in the Association of Geotechnical & Geoenvironmental Specialists (AGS) newsletters (AGS 2021 and 2024) have discussed the concerns of the AGS safety working group about the safety of general trial pitting methods and British Research Establishment BRE 365 infiltration tests. In order to overcome the safety concerns, tests are increasingly carried out using coarse gravel to fill the pit. This provides practical problems and also introduces concerns about the sustainability of waste gravel (in addition to the existing one of water use).

The current BRE 365 test method was first published in 1991 (BRE 1991) and the infiltration test method it describes has not changed since then (despite revisions to the document in 2003 and 2016). The Construction Industry Research & Information Association (CIRIA) Report 156 (CIRIA 1996) did propose some amendments to the test (for example it recommends that the depth of water should be comparable to that likely to occur in the infiltration system and also if soil conditions vary across a site the tests should be undertaken at 10m spacings) but this document is rarely referred to.

At the time BRE 365 was first published, infiltration systems were essentially limited to relatively deep soakaways that cover a small area. They were also only normally used to drain small areas.

Properly designed Sustainable Drainage Systems (SuDS) require shallow infiltration devices dispersed around a site rather than a single large soakaway at the end of a piped drainage system. For these types of system, the BRE 365 test is not suitable. Even for small single soakaways managing runoff from small roof catchments there are better ways than BRE 365 to assess infiltration rates. There are often significant issues with the application of the test method and analysis of the results, as well as no assessment of surrounding ground conditions.

The industry should move from infiltration “testing” to infiltration “assessment”, because determining an infiltration rate is more than just pouring water into a hole. The ground model needs careful consideration and a full assessment using other test methods will give a better overall indication of the infiltration rate of the soil than a BRE 365 test on its own. In the ideal SuDS scenario, many small tests in conjunction with good understanding of the ground model are better than a few large scale BRE tests used in isolation.

A further concern is the unnecessary and unreasonable requirement from some Lead Local Flood Authorities (LLFAs) for infiltration tests to be completed to demonstrate infiltration is not possible.

The BRE 365 test

The BRE 365 test is not particularly accurate for a number of reasons (See Figure 1). There is also often scant regard paid to ground conditions when interpreting results. The dimensions of trial pits in practice are rarely, if ever, perfectly rectilinear and where gravel infill is used the porosity is often assumed rather than measured. However, such theoretical issues and the resulting variations in infiltration rate are not normally the cause of soakaway or infiltration system failure.

The most common cause of failure is that little, if any, attention has been paid to the overall ground model when designing an infiltration test programme and interpretating the results. Tests are often carried out by unqualified staff without any understanding of the ground model and there are often no robust soil descriptions provided.

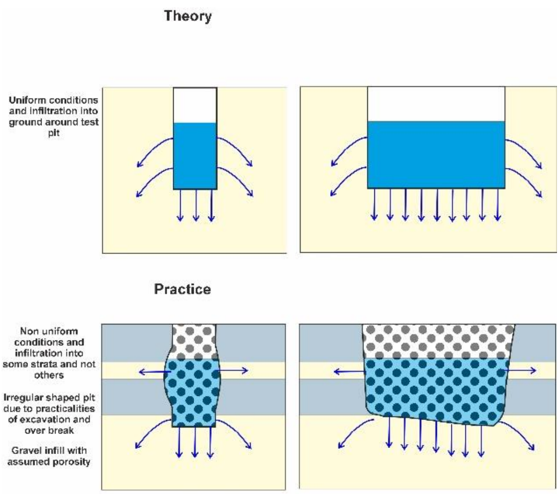

Figure 1 Infiltration testing - theory and practice

The importance of the ground model is recognised in BRE 365 which requires "*Examining site data to ensure that variations in soil conditions, areas of filled land, preferential underground seepage routes, variations in the level of groundwater, and any geotechnical and geological factors likely to affect the long-term percolation and stability of the area surrounding the soakaway*". Unfortunately, this aspect of the design and testing is often ignored.

The main causes of soakaway failures that are ground related (rather than poor construction or other non-ground related design issues) are all related to poor understanding of ground conditions, poor design of the testing or poor analysis of the test results as shown in Figure 2. One very serious issue that is all too common is the analysis of infiltration results in layered ground that follows the method in BRE 365. The BRE solution assumes that the infiltration out of the pit occurs evenly over the whole surface area. It is not appropriate where water only leaves the pit via a discrete stratum (figure 2a). This can underestimate the infiltration rate, leading to larger than necessary infiltration systems. However a more significant issue is where the permeable stratum is of limited extent and the ground is not suitable for soakaways, despite the test indicting it is (Figure 2b). In these cases the analysis method should be amended to take account of the strata in the test pit.

Excessive extrapolation of results where the water does not fully soak away over a working day is also an issue which generally leads to over estimation of infiltration rates (Figure 2c).

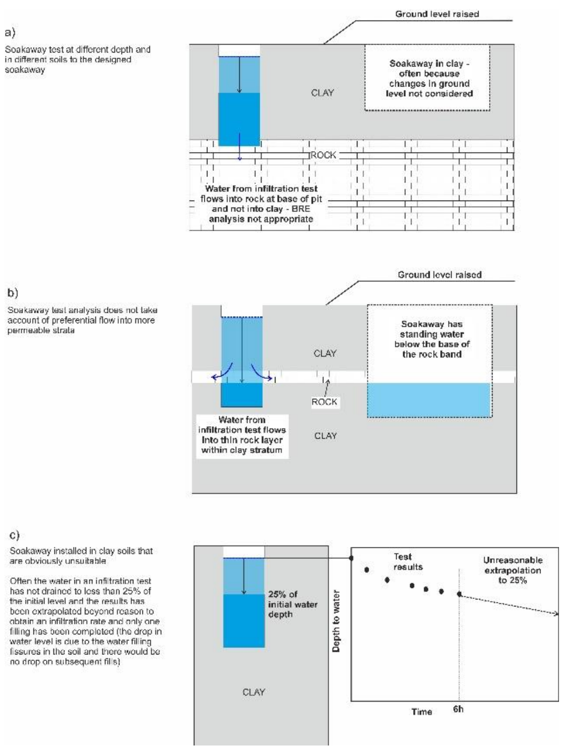

Figure 2 Issues with BRE 365 test results

There is a perception with infiltration testing that "more water and bigger pits" are better. The reason for this is the idea that soils around and below infiltration devices become saturated because of the large volumes of water entering the ground and that the bigger test takes account of the macro structure of the soil and rock and associated variations in permeability.

However, for infiltration SuDS features such as rain gardens, permeable pavements and infiltration basins there is a significant element of "interception" that occurs in the surface layers of the SuDS. This means that for the majority of rainfall events there will be no infiltration to the ground. Rainfall simply soaks into the surface layers and evaporates later.

Fully saturated conditions rarely occur in the soils around and below these types of infiltration systems. During infiltration events, a field-saturated condition develops (which is not full saturation – ASTM 2016). True saturation does not occur due to entrapped air which prevents water from moving in air-filled pores. This may reduce the hydraulic conductivity in the field by as much as a factor of two compared to conditions when trapped air is not present (ASTM 2016). Field test methods should simulate the field saturated condition.

Macro structure will normally only be relevant in strata such as rock or fissured clay (and clay will not be suitable for infiltration). The influence of macro structure or variations in permeability can be allowed for by using a greater number of smaller tests and, more importantly, by robust assessment of the ground conditions by qualified geotechnical engineers or geologists.

Good soil and rock descriptions to BS 5930: 2015 + A1: 2020 (which incorporates descriptions to BS EN ISO 14688 and 14689) are a vital part of infiltration testing. They can be used in two ways.

The first is that initial permeability assessments can be made by designers based on the soil descriptions and published permeability values.

The second is that they are required to allow designers to undertake a sense check on infiltration results, understand whether the normal analysis of the results needs to be amended (eg if all the water lost in the test has gone into a base layer of rock and all the walls are clay) and to provide information for the wider ground model.

Another important consideration is the cut and fill profile of a site. This can result in ground levels increasing or decreasing from those at the time of any site investigations. This needs to be considered when assessing the locations for infiltration tests and the design of infiltration systems.

The SuDS Manual

The key reference for the design of SuDS and infiltration drainage is The SuDS Manual (CIRA C753, CIRIA 2015). One criticism that can be made of this document is that it does not include geotechnical engineers/geologists in the design teams that are required. Previous CIRIA Reports on SuDS (C609) emphasise the importance of a well planned and well executed site investigation where infiltration is to be used. It also recognises the importance of not relying solely on infiltration tests and recommends that the use of soakaways should be assessed by a geotechnical engineer to ensure that ground conditions are suitable.

Appendix B.4 of the SuDS Manual includes a checklist (Table B6) intended for use by the approving bodies (and the designers) of SuDS. This requires design teams to have competence in ground assessments, which again is often not complied with.

Some local authorities and water companies do use the checklist in B6 when assessing whether sufficient information has been provided to allow approval of the design. The National House-Building Council (NHBC) and other Building Control authorities will also ask for geotechnical assessments, for example where infiltration is proposed within 5m of a building.

Unfortunately, despite the requirements in BRE 365 and the SuDS Manual, infiltration testing is seen within the drainage industry as just filling a hole with water and recording how fast it drains away. There is also little understanding of the limitations of the test and that there are viable and safer alternatives that can be used to assess infiltration rates on development sites.

Water Companies

Water and Sewerage Companies (WaSC) are now able to adopt some SuDS including some types of infiltration system. Training to WaSC delivered by Water UK has emphasised the importance of the conceptual ground model for infiltration design and the fact that infiltration assessment is more than infiltration tests. The training also recommended that WaSC require the following to be supplied with any infiltration design:

- Reasonable assessment of geology and infiltration capacity of each stratum by a qualified geotechnical or geology professional;
- Advice from qualified geotechnical or geology professional on suitable depths and infiltration rates (with the stratum to which the rates apply identified);
- Review of final infiltration design by geotechnical or geology professional to make sure it meets the advice provided in the site investigation report; and
- Completed infiltration Checklist – SuDS Manual, Table B.6.

It also advised that there are acceptable alternatives to the BRE 365 infiltration tests such as permeability tests in boreholes.

Alternative test and assessment methods

Is it time to reassess the use of BRE 365 and allow alternative methods of infiltration testing combined with wider assessment of the ground model? Other infiltration test methods are used successfully in other countries and there is no reason why those cannot be used in the UK. A larger number of alternative tests combined with an assessment of the overall ground model and other data will provide a much better indication of infiltration rates than a limited number of BRE tests.

The SuDS manual includes falling head tests to ISO 22282-2:2012 (completed and analysed as a test in the unsaturated zone) as an acceptable alternative to BRE 365 tests. In practice they provide a reasonable alternative to testing in trial pits, providing the results are assessed in the context of the wider ground model by an experience ground engineering professional.

The borehole tests in the unsaturated zone require the ground to be pre saturated before the test, which is similar to the "test three times" approach in BBRE 365.

The AGS article in 2021 suggests that use of boreholes as a device for obtaining infiltration data is a natural ambition for AGS members seeking compliance with standards and health and safety. There is no reason why simpler and safer methods using boreholes, permeameters and ring infiltrometers cannot be used. Indeed, the design of site investigations must comply with the Construction (Design and Management) Regulations 2015. A fundamental principle of the regulations is that of elimination of hazards where possible using less hazardous alternatives. Given that there are acceptable and safer methods of infiltration testing than BRE tests then a site investigation designer is legally obliged to use the alternatives. This should be recognised by LLFAs and Water Companies.

Boreholes tests have been used successfully to assess infiltration rates for retrofit SuDS in streets where BRE tests are not practical.

For permeable paving and infiltration basins the head of water in the infiltration test should be kept low and therefore the use of the alternative methods is more suitable and reliable, which will remove the hazards associated with infiltration tests in deep trial pits.

Existing standards that may be used as guidance are:

- BS EN ISO 22282-5:2012 Geotechnical investigation and testing - Geohydraulic testing - Part 5: Infiltrometer tests), which describes various types of ring infiltrometer test; single or double ring, open and closed. These are used in other countries to assess infiltration from shallow SuDS features such as infiltration basins, permeable pavements and rain gardens (see below). They are generally suitable for testing at shallow depths and would need to be undertaken at the base of a stable and safe pit.
- ISO 22282-2:2012 Geotechnical investigation and testing - Geohydraulic testing - Part 2: Water permeability tests in a borehole using open systems. The ground around the well should be pre saturated and the results analysed as a test in the unsaturated zone. These can be undertaken to any reasonably expected depth for an infiltration device
- ASTM D5126-16 Standard guide for comparison of field methods for determining hydraulic conductivity in vadose zone. Permeameters can be used in boreholes with the common diameters typical of UK site investigations and some are available that can test at depths that can be reasonably expected for infiltration devices.

A summary of examples of infiltration testing used in various countries is provided in Table 1. It is of particular interest that the Scottish Building Standards already allow the use of constant head permeameter tests. There is no justifiable reason why this cannot also apply in the rest of the UK.

In summary all other countries determine infiltration rates using borehole, permeameter or infiltrometer tests.

When should infiltration testing be used?

A further issue is the unreasonable and unnecessary requirement from many LLFAs for infiltration tests to be completed to show that a site is not suitable for infiltration. On many sites it is often not necessary to fill a trial pit with water and sit watching it go nowhere for eight hours, just to show infiltration is not possible. A robust desk-based assessment of the geology and ground conditions by a suitably qualified ground engineering professional can often be sufficient to show that infiltration is not viable. At the site investigation stage if the ground below the site is shown to comprise low permeability strata such as clay there should be no need for tests to show infiltration is not viable.

From a health and safety perspective not requiring infiltration tests in the first place, where they are not necessary, is a good step forward (and follows the accepted CDM hierarchy that the first option to be chosen should be to eliminate the hazard by design if possible).

However, the consultant involved should provide a site specific, robust and well-reasoned argument why infiltration is not possible. Examples of situation where this may apply are:

- Some (not all) sites where ground contamination is present. An example could be where residual hydrocarbon contamination is present that could be mobilised by infiltration drainage. Another example is where a development is located over old landfill material.

Table 1 Infiltration test methods in different countries

Country/Location	Reference	Allowable infiltration test methods
Scotland	Scottish Government, Building standards technical handbook 2022: domestic June 2022	For small single domestic soakaways and non-domestic soakaways Constant Head or Tube Permeameter as described in CEN/TR 12566–2–2005 Infiltration tests in a 300mm by 300mm pit with minimum 300mm depth of water at start of test. Minimum of two tests. Filled and allowed to drain overnight prior to test. Repeat test three times.
USA, California, Riverside County	Riverside County – Design Handbook for Low Impact Development Best Management Practices Appendix A Infiltration Testing. Riverside County Flood Control and Water Conservation District, September 2011	Single and double ring infiltrometer, well permeameter. Site investigation required to determine high groundwater level and thickness of strata being infiltrated into. Report by civil engineer, geotechnical engineer or certified engineering geologist or hydrogeologist required. Tests may be performed only by individuals trained and educated to perform, understand and evaluate the field conditions. Preliminary site grading plans shall be provided to the EA showing the proposed BMP locations along with section views through each BMP clearly identifying the extents of cut/fill relative to native soil.
USA, Indiana	Indiana Office of Community and Rural Affairs, Green Infrastructure Curriculum and Training, Appendix F,	Double ring infiltrometer, permeameter

	Soil Infiltration Testing Protocol	
Australia, New South Wales, Port Stephens	Port Stephens Council, Soil Infiltration, Technical Information Sheet, Rev 3 May 2019	Double ring infiltrometer Also requires tests and assessment to be completed by a qualified and experienced geotechnical engineer that is recognised under the National Engineering Register. Minimum number of tests (See Table 3 below)
Australia, Tasmania, Hobart	Derwent Estuary Program, WSUD Engineering Procedures for Stormwater management in Tasmania 2012, Chapter 10 Infiltration Measures	Falling Head Auger Hole method of Jonasson (1984) Correction factors applied to results to allow for over under or underestimation in different soil types.

Notes

In the USA SuDS are referred to as best management practices (BMPs).

In Australia SuDS are known as Water Sensitive Urban Design (WSUD)

- Sites underlain by a significant thickness of clay that does not include more permeable layers (e.g. Lias Clay in some parts of Northamptonshire).

Permeameter tests

Constant or falling head permeameter tests can be undertaken over the same depths that BRE 365 tests are normally completed. The tests are completed in boreholes which can be drilled by hand or power auger, windowless samplers, cable percussion, etc. More than one test at different depths may be necessary in layered soils (Gill et al 2023).

The test requires significantly less water than a BRE test and is more practical.

Various permeameters are available. The Guelph permeameter and similar instruments maintain a constant head of water above the bottom of the hole and rate of water flow into the soil is recorded at short intervals until it reaches a steady state. The field saturated hydraulic conductivity (K_{fs}) of the soil can then be calculated (Amoozegar 2020). Falling head instruments repeat falling head tests over a short length until a steady state is reached.

A photo of a permeameter is provided in Figure 3. Advantages of using permeameters are:

- The test equipment is relatively lightweight / easy to set up;
- Small volumes of water are required for each test; and
- Tests can be undertaken during drilling or windowless sampling or can undertaken separately from the main site investigation in auger holes, depending on required depth.

Figure 3 Permeameter (EPG Ltd).

A study by Bockhorn et al (2014) compared the infiltration rates obtained using a double ring infiltrometer, a Guelph permeameter and a trial pit test. Details of the tests are shown in Figure 4. All the tests were in Glacial Till comprising clay.

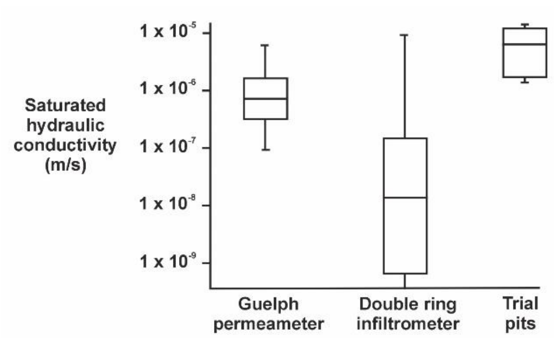

Figure 4 Comparison of saturated hydraulic conductivity from various tests (redrawn after Bockhorn et al 2014)

The trial pit tests were not repeated three times as per BRE 365. The pits were filled with water until a steady state outflow was attained and the infiltration recorded. The time to achieve this is not stated. The infiltrometer gave the lowest results followed by the Guelph permeameter and the highest results were from the infiltration pit. Two of the permeameter tests gave no infiltration at all which may have been due to compaction of the soils by machinery or just inherent variations in the Till across the site.

The possible reasons for the trends observed were considered to be smearing on the sides of the hole, compaction of the soils close to the surface and the fact that the pit would include infiltration via fissures in the clay and variations in soil grading.

However, it was also considered that the pit had not fully saturated the ground around it whereas the infiltrometer and permeameter tests had. It is known that typically in a BRE 365 tests the infiltration rate reduces from initial to third repeat of the test, typically by one order of magnitude. This would make the pit test results comparable to the Guelph permeameter results.

The infiltration rate of soils can show spatial variability due to the inherent heterogeneity. However, this can be managed by using a suitable number of tests. The authors concluded that use of infiltrometer or permeameter tests alone would not provide a reliable indicator of infiltration rates. They concluded that data from pits gave more representative results but that the pits are highly invasive. However probably the most significant reason for the variations that was not discussed is the limited number of pits (four) in one area of the site compared to the number of permeameter and infiltrometer tests (19 and 18 respectively spread over a much wider area of the site).

The authors concluded that the most appropriate infiltration test method was to use the tests in conjunction with borehole soil descriptions and geological assessment of the ground. This requirement already applies to BRE 365 tests (but is often not followed). Given the small difference between the permeameter tests and the pit tests and also accounting for saturation, it is considered that the results show that a larger number of permeameter tests and a robust assessment of ground conditions by a ground engineering professional is a reasonable alternative to BRE 365 tests. In any event, as discussed earlier, even BRE tests should be accompanied by a robust assessment of ground conditions.

The Irish Environmental Protection Agency (EPA – Government of Ireland, 2023) has conducted research on alternatives to percolation tests for wastewater infiltration systems. The research included a comprehensive literature review of soil permeability testing and design standards for onsite wastewater treatment systems. The study involved assessment of a database of falling head tests in pits (over 900 tests), modelling and field tests to compare the different methods at 17 sites. In summary it was conclude that falling head infiltration tests in pits (a version of the BRE 365 test, but in smaller pits) is not an ideal method and should be replaced. Constant head tests using permeameters are considered more reliable and practicable. It also emphasised that international guidance indicates that insitu permeability tests should only be used as a complement to detailed site assessments. Permeability test results should not be the main factor in assessing suitability for infiltration and there is a need for the results of the tests to be placed in the context of an accompanying assessment of the soil texture and structure.

Conclusion

The BRE 365 infiltration test has significant health and safety, practicality and sustainability issues. There are suitable alternative methods that are used by some in the UK and that are also widely used in other countries. Large scale pit infiltration tests are rarely, if ever, used in other countries to determine infiltration rates for SuDS.

The key to successful infiltration testing and design is to include a suitably qualified ground engineering professional in the SuDS design team to advise on the appropriate test methods and to interpret the results. They should also review the final design with reference to the site ground model.

The way forward to support a sustainable agenda, reduce waste of valuable natural resources and improve health and safety is to:

- Promote wider use of understanding ground models at the initial design stage and not to preferentially rely on limited study and a small data set of BRE 365 infiltration tests.
- Avoid doing infiltration tests where the desk study information and preliminary assessment shows it is not viable (from a CDM perspective design out the hazard, which should be the priority);
- Use borehole, permeameter or infiltrometer tests as appropriate, if possible (design out the hazard from the testing).
- Even for larger systems consider the use of a greater number of borehole tests rather than limited BRE tests. Consider the benefits of a good geological characterisation and what benefits could be gained from having high quality data rather than the adoption of worst-case values because of limited data.
- Only use BRE tests when absolutely necessary and infill the pit with gravel to remove the hazard. Use data loggers for water level recording.

Furthermore, the analysis of infiltration test results should not blindly follow the assessment in BRE 365. If layered soils are present where water preferentially infiltrates into one layer this should be allowed for and stated. Infiltration test results should state which stratum they are applicable to. The tests should also be related to an ordnance datum level so that designers can take account of changes in ground level due to cut and fill.

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