Temporary Works Toolkit

Part 12: Dealing with risks from groundwater – guidance for design engineers

The Temporary Works Toolkit is a series of articles aimed primarily at assisting the permanent works designer with temporary works issues. Buildability – sometimes referred to now as 'construction method engineering' – is not a new concept and one always recognised as vital to the realisation of one's ideas; it ought to be at the forefront of an engineer's mind.

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Stephen Thomas, Graham Richardson and David Fletcher of OGI Groundwater Specialists provide an introduction to groundwater risks for permanent and temporary works designers.

Introduction

When designing any structure where deep excavation is required (shafts, tunnels, deep basements, tanks and pipework infrastructure, etc.), it is essential that design engineers understand the significance of the risks associated with groundwater.

Under the UK Construction (Design and Management) (CDM) Regulations, it is the responsibility of the permanent works designer to identify, eliminate or minimise all foreseeable risks which may occur during the construction phase of the project, providing a safe method of construction.

As such, there is an obligation on the permanent works designer to understand the groundwater risks associated with both the temporary and permanent works.

Uncontrolled groundwater during temporary works can cause ground instability, loss of building integrity, health and safety issues, programme delays and additional costs (Figure 1).

This article provides guidance on how to deal with groundwater risks for both permanent and temporary works designers. It aims to:

- identify some of the groundwater risks commonly encountered during temporary works and explain why knowledge of these risks is essential to designers
- enable designers to assess whether there is a groundwater risk that needs to be addressed
- enable designers to identify when guidance from a groundwater specialist is needed
- provide an awareness of the main groundwater control options available.

Figure 1 Slope instability due to weak, saturated ground

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Identifying groundwater risks

Mitigating groundwater risks during temporary excavations in saturated ground is crucial to the overall success of a project. Table 1 identifies a number of groundwater hazards commonly encountered during temporary works, together with their potential consequences, and the risks they may present to a project. Significant delay and additional project costs can result if groundwater hazards are not adequately addressed.

TABLE 1: COMMON TEMPORARY WORKS GROUNDWATER HAZARDS, CONSEQUENCES AND RISKS

Temporary works hazard	Potential consequence	Risk to project
High water table	Flooding of site	Damage to plant and equipment; increased spoil disposal; increased cost; difficult working conditions; delays; health and safety; claims; prosecution
	Low effective stress of the ground and consequently low shear strength Running sand	Settlement and ground instability; inability of the ground to support load; failure of natural and battered slopes; damage to existing services and structures; prosecution
	Mobilisation of pollutants within the ground	Environmental contamination; project delays; prosecution
	Buoyancy	Flotation of structures prior to application of final load
	Inability to excavate	Delays and additional costs to the project
High water table around the excavation	Increased lateral pressures on retaining walls	Higher specification wall requirement at greater cost
High piezometric level	Uplift forces due to groundwater pressures exceeding load weight on the base	Damage to base slab; flotation of structures prior to the application of permanent load; flotation of structures when permanent load is removed (i.e. during cleaning of tanks)
	Flooding of site	See 'Flooding of site' risks
Vibration of plant and traffic	Liquefaction	Differential settlement in and around structures; inability of ground to support loads

Why should permanent works designers understand temporary works groundwater risks?

For a typical project, the designer of the permanent works will normally issue a preliminary design which is put out to competitive tender. The pre-tender documents may occasionally identify that some degree of groundwater control is needed, but typically will only include a site investigation report. It is left to the main contractor to determine the significance of any groundwater risk and what groundwater control measures are required.

In practice, the tendering main contactor rarely possesses the in-house expertise to adequately assess groundwater risks and control requirements. Responsible main contractors will consult a groundwater specialist for advice. Adequate funds to cover the cost of appropriate groundwater control measures are then incorporated into their tender.

However, the reality is that responsible main contractors are in competition with other tendering main contractors, some of whom may fail to recognise, or underestimate, the groundwater risks present. Other main contractors may recognise that there are risks, but are prepared to gamble that they can tackle the groundwater issues using a sump pump.

When tenders are awarded based primarily on cost, responsible main contractors are placed at a competitive disadvantage. Award of a project to a cheaper bid that does not allow adequately for groundwater control can place the project at serious risk.

Figure 2
Sump pump dewatering on site. Large grey discharge pump hose emerging from sump

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Benefits of understanding risks

If groundwater risks are adequately understood by the permanent works designer, with assistance where necessary from a groundwater specialist, significant project benefits can be realised. For example:

- A preliminary groundwater control strategy can be put in place at pre-tender stage, so that tendering main contractors can include for the same groundwater control measures required, on a competitively equal basis.
- By combining the temporary and permanent works groundwater solutions, significant cost savings to the project can be made, thus avoiding duplication of effort and resources.
- By combining the temporary and permanent works groundwater solutions, an opportunity exists for innovative approaches to groundwater control. In our experience, this is where real efficiency and cost savings can be made to the project.
- Permanent works designers are able to meet their CDM buildability obligations, and significantly reduce the project's exposure to risk.

Is there a groundwater risk?

By working through the checklist presented in Box 1, permanent and temporary works designers can be guided to make their own initial assessment of whether their project is likely to require groundwater control.

Note that while some of the questions listed in Box 1 may seem simplistic, in our experience failure to address these points can result in errors that can significantly impact on the success of the project.

Controlling groundwater

Once all the checks detailed in Box 1 have been conducted, if groundwater risks have been identified (high water table and/or artesian pressure), then appropriate groundwater control measures are required. These may include:

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Figure 3
Wellpoint dewatering. Installation on site, using jetting tube

- construction dewatering
- installing cut-off or diaphragm walls
- pumping grout into the pore spaces to reduce the groundwater inflow
- freezing the ground to immobilise groundwater outside the excavation.

In the majority of cases, the groundwater inflow into an excavation is managed by a combination of construction dewatering and impermeable cut-off walls.

The following provides a brief description of the main methods of construction dewatering.

Designed sump pumping

Sump pumping is a quick and simple method of removing perched water and can lower the water table to relatively shallow depths.

A sump is constructed below the water table by excavating a shallow hole, into which is placed a slotted pipe surrounded by a suitable filter medium. Selection of filter medium is important to ensure clean, silt-free discharge water. A suction hose attached to a surface suction pump or an electrical submersible pump is placed in the sump (Figure 2).

In some cases, two or more sumps can be used to progressively lower the water table. As one sump becomes redundant (because the water table has been reduced below the level at which it is effective), the redundant sump can be reinstalled at greater depth.

The depth of each sump is typically controlled by the depth that can be excavated without side collapse of the ground, typically 1–2m below the water table.

Wellpoint dewatering

Wellpoints are typically installed using a jetting tube suspended by a 360° excavator (Figure 3). Pressurised water is injected down the jetting tube, creating a hole in the ground into which the jetting tube sinks. When the required depth has been achieved, the wellpoints are installed, consisting of a riser pipe with a wellpoint filter tip fitted to the base. Suitably graded filter sand is placed around the filter tip and the wellpoint. The jetting tube is then removed, leaving the wellpoint and filter medium behind. Individual wellpoints are attached to a header pipe connected to a suction pump.

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Figure 4
Shallow-well suction pump dewatering (along right margin of image) with header pipe (orange pipe) connected to shallow well riser pipes

In good ground, wellpoints can be installed relatively quickly and cheaply, typically spaced every 1–2m. Wellpoints can be used to lower the water table by up to 7m below ground level (but more typically up to 5m below ground level) in soft-to-firm soils or loose sandy soils. Wellpoints are particularly suitable for long, shallow excavations such as pipelines.

Shallow-well suction dewatering

Shallow wells are typically installed using a drilling rig. A dewatering well is then installed into the drilled borehole. A designed filter medium is placed within the annulus between the well casing and the drill casing, and the drill casing is removed, leaving behind the well casing and filter medium.

A riser pipe is installed inside the well casing, which is connected to a header pipe and suction pump (Figure 4). Compared to wellpoint systems, shallow wells are typically installed to greater depth, but significantly fewer wells are normally required to achieve similar drawdown.

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Figure 5
Wellhead of deep well being used for borehole pumping

Suction wells are ideal for lowering the water table, typically by up to 7m below ground level, in ground conditions ranging from soft soil to solid rock. Selection of an appropriate drilling technique is important in hard ground. Shallow wells are suitable for dewatering shallow excavations, shallow shafts and structures.

Deep-well borehole pump dewatering

Deep wells are installed in the same way as shallow wells. However, unlike shallow wells, the pumping system consists of electrical submersible borehole pumps installed close to the base of the wells. A riser pipe connects the pump to the discharge system (Figure 5).

BOX 1. CHECKLIST TO IDENTIFY AND ASSESS GROUNDWATER RISK

1. How deep is the excavation?
The first step is to identify the deepest part of the excavation. This may simply be general formation level. However, remember to consider the following:

a) Are any structures below general formation level?
- Crane pits, pile caps, lift pits, sump pits for permanent pumping, inspection chambers and local drainage or pipework connections.

b) Are reference levels inconsistent?
- Are levels collected from different drawings and reports referenced to the same or differing datum levels? Levels may be expressed relative to: ordnance datum (OD), site datum (SD), chart datum (CD), below ground level (bgl), etc.
- Has a reduction or increase in ground level occurred since the levels referenced to ground level were provided? e.g. piezometers are often installed at original ground level, but the monitoring results can be taken sometime after and may be relative to reduced or raised ground level.

c) Are drawings simply unclear or blurred?
- Are the drawings provided photocopies of photocopies?
- Does the drawing have a quoted scale that does not match the actual scale due to enlargement/reduction during copying?
- Is the text in drawings and documents blurred or too small to read?

If you have answered 'Yes' to any of the above questions, it is recommended that a review be conducted to ensure that the lowest dig levels are determined relative to a common datum level. It is not considered necessary to seek professional advice with these issues. Analysis can be conducted in house by an experienced, careful and competent engineer.

2. What is the level of the water table?
The next stage is to identify the highest expected level of the water table. When examining groundwater measurement/monitoring data, consider the following:

a) Is it possible that:
- Water table measurements are not expressed relative to a common datum level or known ground level?
- Water level measurements in boreholes or piezometers do not represent the 'water table' but are instead measurements of rising groundwater? This can be checked in the borehole logs, which may show that the groundwater level rises 20 minutes after a borehole water strike.

b) Is it possible that there are environmental changes that could affect the water table such as:
- Water table levels rising during a wet winter?
- Water table levels rising during a wet year?
- Tidal changes in water table in coastal and estuarine locations?
- Surface flooding dramatically and suddenly impacting on water table levels?
- Site investigation conducted during a period of dewatering or pumping on an adjacent site?
- Termination of pumping from nearby boreholes?
- Changes occurring in the groundwater regime caused by local underground construction?

If you have answered 'Yes' to any of the above questions, it is recommended that a rigorous review is conducted to identify the worst-case water table level. A professional appraisal is not necessarily required if an in-house, experienced hydrogeologist is able to undertake the review.

3. Does artesian pressure exist below the excavated formation?
Artesian pressure can remain an unseen risk to a project unless it is properly assessed. The final stage of assessment is to establish whether artesian groundwater pressure is present beneath the site.

a) Are there any of the following early indicators that flowing artesian groundwater pressure may be present?
- Is there a known underlying aquifer present below the excavation?
- Are there sealed deep piezometers or boreholes, which indicate artesian head rising to above ground level?
- Are there road names such as 'Well Street', 'Fountain Bridge' or 'Flood Lane'?

The next stage is to consult site investigation reports and any available monitoring data. If no borehole logs or groundwater monitoring data exist, it is highly advisable to carry out a new site investigation. If artesian conditions are identified:

b) Do the borehole logs or groundwater measurements show the 'piezometric level' or merely the rise of groundwater in the borehole after 20 minutes? (The level could and does often rise significantly higher than this value.)

c) If artesian conditions are identified, consider the following:
- Is there insufficient clay thickness between the excavation and the underlying artesian aquifer?
- Are there connecting pathways between the excavation to the artesian layer such as SI boreholes and/or sheet piles?
- Is there insufficient weight on the base slab to prevent uplift damage?

If you have answered 'Yes' to any of the above questions, it is recommended that a rigorous review regarding the potential dangers and associated risks of artesian pressure is conducted. Due to the potential destructive impact of high artesian pressure, we recommend that the review is conducted by an experienced and competent groundwater specialist.

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Figure 6
Ejector method of dewatering being used on site, with series of flow and return header pipes connected to series of wells

Deep-well borehole pumping systems are ideal for lowering the groundwater level where required drawdown exceeds the capability of a suction pump. The depth to which a borehole pump can be operated is limited by the selected pump's technical specifications. Some borehole pumps can operate at depths hundreds of metres below ground level.

Deep-well systems in combination with borehole pumps are suitable for most deep shafts, excavations, tunnels, etc. They can be used in almost all ground conditions except in relatively impermeable ground, where low groundwater pumping rates can cause some pumps to overheat and burn out.

Ejector dewatering
Ejector systems are installed in deep wells where the ground is of low permeability and groundwater flows are very low.

A series of ejector wells are connected to two parallel header pipes, one of which is a high-pressure supply line and the other is a low-pressure return line (Figure 6). Water is pumped under pressure to the ejectors installed at the bottom of the wells. This creates a Venturi effect in the ejector, which in turn induces a flow of groundwater from the ground into the ejector. From the ejectors the water returns up to the header pipe, into the header tank and then on to the disposal point.

Risks associated with groundwater pumping
It is important to note that pumping of groundwater carries its own risks. Before doing so, consider the following questions:
- Is there a requirement to discharge potentially large volumes of water to the local sewer network or local water courses?
- Is there sufficient space available for a dewatering system within the excavation?

- Is there sufficient space surrounding the site for the installation of an external dewatering system?
- Is there a possibility of groundwater contaminated with silt being discharged to a sewer or to the natural environment, i.e. rivers or streams?
- Will lowering the water table below surrounding properties result in real or perceived settlement?
- Could there be groundwater piping and consequential ground failure around the toe of an impermeable cut-off wall or shaft?
- Might it be necessary to dispose of contaminated groundwater resulting in an expensive decontamination operation?
- Is groundwater abstraction and disposal permission required from the regulatory authorities?
- Could ground heave of the excavation base occur, caused by high artesian pressures beneath formation level?
- Will noise restrictions limit the choice of pumping system?

It is recommended that, unless there is in-house specialism, the risks associated with a potential dewatering scheme should be discussed first with a groundwater specialist.

Conclusions

Identification and control of groundwater risks is essential to the success of a project. Early-stage assessment of groundwater risks by permanent works designers, along with development of an appropriate groundwater control strategy, can ensure that CDM obligations are met and that tendering main contractors are able to compete on an equal basis. This approach can considerably reduce risk to the project.

Permanent and temporary works designers can use the checklist presented in Box 1 to guide them through the process of making an initial assessment as to whether there is a groundwater risk to the project.

If groundwater risks are identified, unless there is in-house groundwater expertise, it is recommended that a qualified and competent groundwater specialist is consulted. The groundwater specialist can provide a preliminary groundwater control strategy, to provide an effective, costed solution appropriate for the project. This can be developed further with the selected main contractor following award of the project.

The cost of a professional review of the groundwater risk and appropriate groundwater control strategy far outweighs the potential detrimental consequences to the project.

Significant project savings can be made by combining temporary and permanent works solutions.

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