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Optimisation of dewatering systems

L'optimisation des systèmes de dénoyage

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ABSTRACT : Dewatering systems involve the use of wells to lower groundwater levels, or low permeability cut-off walls to exclude groundwater, so that excavation and can be done in dry and stable conditions. There are a wide range of options for the design and implementation of such systems, and strategies to optimise dewatering systems are of interest to designers. Potential optimisation approaches include: empirical (experience and rules of thumb); numerical/analytical (calculation and/or modelling); and observational (field measurements). There is no perfect optimisation method to address all the possible priorities for a dewatering system, and different aspects of optimisation may conflict, with a need for trade offs between different factors of design. The required conditions for effective optimisation of dewatering systems include: clarity of the objectives of optimisation; adequate site investigation data; development of a valid hydrogeological conceptual model; and, selection of the most appropriate dewatering method at an early stage of optimisation.

RÉSUMÉ. Les systèmes d'assèchement impliquent l'utilisation de puits pour réduire les niveaux d'eau souterraines, ou l'utilisation des murs parafouille à faible perméabilité pour exclure les eaux souterraines, ainsi que l'excavation peut se faire dans des conditions sèches et stables. Il ya plusieurs options pour la conception et l'implémentation de ces systèmes, et les stratégies pour optimiser les systèmes d'assèchement interessera les concepteurs. Les méthodes d'optimisation potentiels incluent: empirique (l'expérience et les règles générale); numérique / analytique (le calcul et / ou la modélisation); et d'observation (le mesures sur le terrain). Il n'existe pas de méthode d'optimisation parfaite pour aborde toutes les priorités possibles pour un système d'assèchement, et les différents aspects de l'optimisation peuvent être contradictoires,, donc il peut y avoir un besoin de compromis entre les différents facteurs de conception. Les conditions requises pour l'optimisation efficace de systèmes de d'assèchement sont les suivants: clarté des objectifs d'optimisation; données adéquates d'enquête du site; le développement d'un modèle conceptuel hydrogéologique valide; et la sélection de la méthode d'assèchement au stade précoce possible d'optimisation.

1 INTRODUCTION

Dewatering is often required to allow excavations to be made in dry and stable conditions below groundwater level. Dewatering systems typically involve pumping from an array of wells or sumps to lower groundwater levels, and may also involve low permeability cut-off walls to exclude groundwater.

On any given site there may be several possible configurations of dewatering system in terms of number and location of wells, cut-off walls, pump capacity and other system parameters that will achieve the required lowering of groundwater levels within the excavation. With the widespread availability of computing power in everyday geotechnical engineering it has become fairly straightforward to analyse multiple groundwater flow scenarios (either as spreadsheet-based analytical models or numerical groundwater models) and apply these scenarios to dewatering design.

It is a logical step to go from analysing multiple scenarios to deriving an 'optimal' dewatering design, typically based on optimising the number of wells or the pumped flow rate. Numerical solutions to optimal dewatering design were tried as early as the 1970s (Aguado et al. 1974), and since then have developed along with emerging numerical decision making tools of their time, such as expert systems (Davey-Wilson 1994), multi-attribute decision analysis (Golestanifar & Ahangari 2012) and artificial neural networks (Ye et al. 2012) amongst others.

Previous studies have often taken a fundamentally mathematical approach to optimisation, in many cases in an attempt to provide better reliability or consistency in dewatering design, in part by reducing the role of 'expert judgment'. The current paper will take a different approach to look at the challenges and pitfalls of optimisation of dewatering systems and will discuss non-numerical optimisation strategies.

2 WHAT IS DEWATERING?

The geotechnical process commonly known as dewatering is more correctly described as groundwater control. There are two principal groups of groundwater control technologies as shown in Table 1.

Table 1. Groundwater control methods

Pumping methods	Exclusion methods
Sump pumping	Steel sheet-piling
Vertical wellpoints	Vibrated beam walls
Horizontal wellpoint	Cement-bentonite or soil-bentonite slurry walls
Deep wells with submersible pumps	Concrete diaphragm walls
Ejector wells	Bored pile walls
Passive relief wells	Grout curtains (permeation grouting; rock grouting; jet grouting; mix-in place methods)
Electro-osmosis	Artificial ground freezing

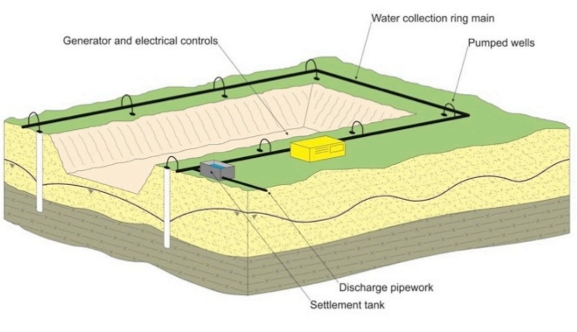

Figure 1: Groundwater control by pumping

The first group is pumping methods where groundwater is pumped from an array of wells or sumps (Figure 1) to temporarily lower groundwater levels. The second group is exclusion methods that use low permeability cut-off walls to exclude groundwater from the excavation (Figure 2). Pumping and exclusion methods may be used in combination.

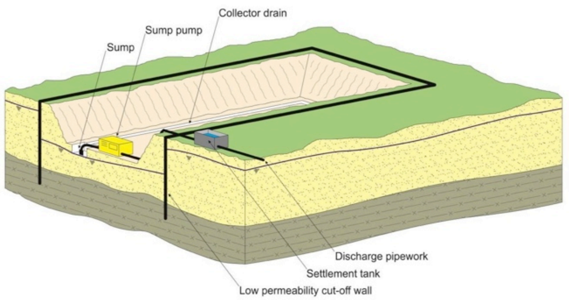

Figure 2: Groundwater control by exclusion

3 WHY OPTIMISE?

Groundwater control is one of first geotechnical processes required on a project, and is often the first that must be proven to allow work to proceed. If groundwater control does not work effectively, or causes delays, these problems will occur at the start of the project, and these can critically affect later stages of construction. The cost of resultant delays can be many times greater than the cost of the groundwater control works themselves (Roberts & Deed 1994).

In contrast to many other forms of geotechnical processes, dewatering design is not covered in detail by geotechnical design codes. For example the dewatering section in Eurocode 7 (BS EN 1997-1 2004) is only one page long, and there is no corresponding execution standard for dewatering. Dewatering guidance documents do exist in the UK (Preene et al 2000), United States (Unified Facilities Criteria 2004) and the Middle East (ASHGHAL 2014; Abu Dhabi City Municipality 2014), but tend not to be prescriptive and are typically in the form of 'toolkits' of design methods and construction techniques. Therefore at the start of a project designer can be faced with a bewildering arrangement of design and implementation options, and a rational optimisation approach can look attractive.

Any attempts to optimise the design of dewatering systems must be appropriate to the design method used.

4 METHODS OF OPTIMISATION

There are four main approaches to dewatering design and optimisation:

- Empirical: A design based largely on experience, local knowledge and ‘rules of thumb’.
- Analytical: Use of hydrogeological design equations, either manually or by spreadsheet.
- Numerical: Use of 2 or 3 dimensional numerical groundwater flow models.
- Observational: Use of construction observations to design and refine the dewatering system.

4.1 Empirical optimisation

Optimisation by empirical methods has been successfully used on many simple projects. A simple project can be defined as one where: the hydrogeological conditions are well defined and relatively straightforward; where the excavation is relatively small and shallow; and, where environmental impacts are not a key concern. Examples might include shallow basements, pipeline projects, sewers, etc.

Empirical optimisation uses experience of previous projects nearby or in comparable conditions. The dewatering method, flow rate and drawdown of a previous project can be used to optimise another project where the conditions are comparable.

When geotechnical engineers become involved in dewatering design, the use of empirical design is sometimes viewed as being less rigorous compared to numerical or analytical methods. However, there is a huge track record of empirical methods providing successful dewatering designs. One of the reasons why this is the case is that, provided the correct groundwater control method is selected, a given dewatering technology can often successfully deal with modest variations in ground conditions. This is illustrated by Figure 3, which shows that individual methods are appropriate for a relatively wide range of drawdown and hydraulic conductivity conditions. Conversely, this highlights the limits for each dewatering method beyond which it is not effective. It is essential to select the correct dewatering technology for a project.

The empirical method requires sufficient site investigation data to allow the hydrogeological conditions to be identified, as well as relevant experience from comparable projects. Adequate site investigation data are essential to characterise site conditions, otherwise it cannot be known whether the previous sites, from which experience is drawn, are comparable. In practice, when problems occur with dewatering systems optimised by the empirical method, this is often due to applying empirical rules between sites where underlying conditions are different.

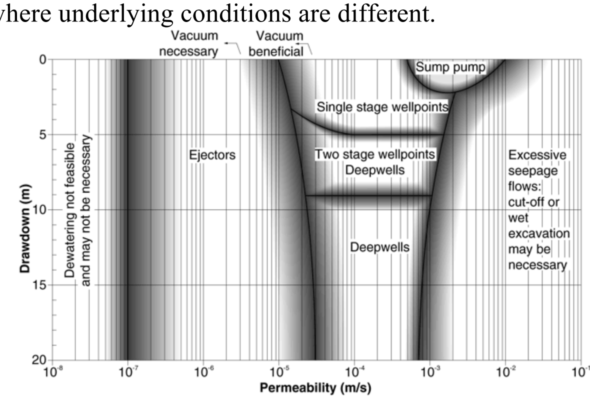

Figure 3: Range of application of pumped well groundwater control techniques (from Preene et al. 2000: reproduced by kind permission of CIRIA)

4.2 Numerical modelling or analytical optimisation

Numerical modeling is used far more in dewatering design and optimisation than it was 10 years ago. This popularity is because the necessary investments in software, hardware and training have reduced dramatically, and also because modern software can easily demonstrate results visually for non-technical project clients. Numerical modelling offers the flexibility to take into account known or inferred variations in the aquifer within the range of influence. This might include assessing the effects of a nearby river, another dewatering project, or a natural barrier in the aquifer.

The analytical approach uses hydrogeological equations (as might be found in a textbook) to estimate pumped flow rates and drawdowns. It is typically suited to relatively simple hydrogeological conditions with few complex boundaries (rivers, faults, other abstractions). Each set of analytical equations is only applicable to a relatively narrow range of hydrogeological boundary conditions, and gross errors can result if used in the wrong conditions.

Both modeling and analytical approaches need to be applied based on a 'hydrogeological conceptual model' which captures the important features of the groundwater system at the site and its environs. The conceptual model will normally be developed directly from the site investigation data, including a hydrogeological desk study. If the conceptual model is inaccurate or incomplete, the results of any subsequent modeling or analysis are likely to be erroneous.

4.3 Observational optimisation

Perhaps the ultimate expression of optimisation is the observational method. Construction observations (for example pumped flow rates and groundwater drawdown levels) are used to guide optimisation of the system as part of a deliberate process of design, construction control, monitoring and review (Nicholson et al. 1999). The observational method is sometimes combined with 'inverse numerical modelling' where series of numerical modelling scenarios are prepared in advance for a range of possible hydrogeological conditions and then compared with the field data.

The observational method can be useful to deal with local variations in ground conditions. On larger projects it may be the best solution to address these variations locally (using the flexibility of the observational method) instead of engineering the overall system based on the worst-case conditions, as might be necessary if the dewatering system was conservatively designed at the start with little flexibility.

4.4 Optimisation in the field (troubleshooting)

Occasionally, dewatering systems are not effective when initially installed, and a 'troubleshooting' investigation is needed. This approach takes place during construction, and so has access to field data (e.g. dewatering well logs, pumped flow rates, drawdown water levels) that were not available to the original designer. These data need to be reviewed to identify whether the lack of performance is related to: 'unexpected ground conditions' (i.e. ground conditions different to the assumed conceptual model); operational problems with the current system (e.g. existing pumps and wells not delivering their design capacity); or the fundamental issue of the wrong dewatering technology or approach being used. The objective of troubleshooting is to develop a plan of action, to develop an effective dewatering system at the site, suitable for current conditions.

5 PROBLEMS WITH OPTIMISATION

A wide range of problems can occur when dewatering systems are optimised, as outlined below.

5.1 Lack of clarity in objectives of optimisation

A fundamental problem with dewatering optimisation is lack of clarity in the objectives of optimisation, and failure to recognise that optimising in one aspect may require compromises in other aspects.

Traditionally, dewatering optimisation has focused on optimising pumping rates (i.e. to avoid pumping water unnecessarily) while still achieving the required lowering of groundwater levels. This has the advantage that it will likely also minimise operational costs and energy consumption. However, if pursued single-mindedly this approach could result in a dewatering system with little spare capacity to deal with modest changes in ground conditions that may require higher pumped flow rates. Also, such a system might be designed without consideration of environmental impacts on the groundwater regime; increasingly the minimisation of impacts is a necessary design consideration.

5.2 Data quality and quantity

The data from site investigation and previous projects are the foundation of the conceptual hydrogeological model and all subsequent calculations, modelling or analysis and dewatering system design. If these data are inadequate in quality or quantity everything after this step will be of limited value. No modelling effort can correct false or poorly determined parameters.

- Data quality: This can be a very subjective issue and relates to how reliable the data are perceived to be. There can be issues with the source of the data (e.g. by whom was the work carried out and how is it reported) or questions over internal consistency of the data (e.g. if borehole logs describe a sandy gravel, but the hydraulic conductivity tests report very low values).
- Data quantity: There are two issues, is there enough data and are the relevant issues ad-

dressed? There should be sufficient data to develop some understanding of the likely variations in ground conditions. Here a geological desk study can be of great value to help identify the likelihood of local geological variations. The relevance of the data relates to whether the necessary information is provided. For example, is information available from the right parts of the site and from the relevant strata? A common issue is: are the site investigation boreholes deep enough to identify the presence of any confined aquifers beneath the base of the excavation that could cause an uplift hydraulic failure of the base?

A valid part of dewatering optimisation may ultimately be to recommend additional ground investigation to plug any identified data gaps, and/or to recommend that the dewatering system be implemented by the observational method to provide flexibility against variations in ground conditions.

5.3 Errors in conceptual model

As has been described elsewhere in this paper, getting the conceptual hydrogeological model correct is fundamental to the design and optimisation of dewatering systems. Many significant dewatering problems can ultimately be traced back to an inappropriate conceptual model that either leads the designer down the wrong design avenue, or causes the designer to ignore a design condition that is, in fact, important. Examples include:

- Failure to identify layers of low vertical permeability beneath the base of an excavation, which may create a risk of unrelieved pore water pressures at depth, which could cause base failure.
- Failure to identify that the range of hydraulic conductivity potentially includes soils of low permeability that will limit the flow rates yielded by pumped wells.
- Failure to identify groundwater contamination in the vicinity of a dewatering system that may be mobilised by pumping.

If these conditions are not identified then modelling or analysis will not address the relevant questions, or will use unrealistic parameters. A common modelling problem is where the well yields used in a numerical model are unrealistically high. For example, a very large excavation in a fine sand might require a total flow rate of 50 l/s. In fine sands the yield of an individual deep well pumped by a submersible pump will typically be limited by the hydraulic conductivity of the sand to between approximately 1 l/s and 5 l/s. But it is possible for an analyst to model the system as based on say five wells at 10 l/s. In theory this would achieve the overall flow rate, but in the real world these well yields would never be achieved, and a five well system would be ineffective. Such problems can occur when designers are not familiar with the operational characteristics of dewatering wells and systems. While manufacturers of dewatering equipment do publish pumping capacities these rates are effectively 'ideal' values that do not take well yields into account. It is important that any modelled dewatering system is critically reviewed against realistic pumping parameters.

5.4 Inappropriate dewatering method

As discussed earlier, and shown in Figure 3, each type of pumped dewatering method is applicable to a finite range of ground conditions. If an unsuitable dewatering method is selected at the outset of design (e.g. if ejector wells are used in a high permeability soil) then even extensive and detailed optimisation measures are likely to be futile.

It is essential that designers and analysts have an understanding of the limits of performance of the chosen dewatering system, and consider this in design. For example, if the chosen dewatering method will be effective not just for the 'design value' of hydraulic conductivity, but also for the 'highest credible' and 'lowest credible' values then the design is likely to be robust. However, if relatively small changes in hydraulic conductivity may require a change in pumping method this can cause major delays and cost overruns to a project.

6 POSSIBLE PRIORITIES FOR OPTIMISATION

Traditionally, the main priority for dewatering optimisation is to reduce installation costs or occasionally to meet regulatory requirements, such as when a limit has been set on the maximum permitted discharge rate. Increasingly, there is also a focus on developing effective dewatering systems that have minimal environmental impacts (such as ground settlement). However, there are several different strategies that can be adopted for optimisation, as shown in Table 2.

A common factor with many dewatering systems is that a higher flow rate is needed during the early period (the first days or weeks) of pumping. It is not currently common practice to modify a dewatering system to reduce pumping capacity, for example by removing some pumps or reducing pump size, after the initial drawdown period. It is possible to use field measurements, inverse numerical modelling and risk assessments to estimate the reduction in pumping capacity that can be achieved while still being capable of handling the worst credible hydrogeological conditions. There are significant potential energy savings by optimising long-term capacity in this way.

Table 2: Possible aspects of groundwater control for optimisation

Optimisation priority	Comments
Lowest pumping rate	Risk that system will not have sufficient spare capacity to handle modest increases in flow rate above design values.
Lowest energy usage	Will tend to favour lowest pumping rate solutions, with the same risks. May involve use of smaller pumps for steady state pumping, once initial drawdown has been achieved.
Minimal impacts	May favour groundwater exclusion solutions that use low permeability cut-off walls to avoid or minimise pumping.
Minimal capital cost	Will tend to favour lowest pumping rate solutions, with the same risks.
Minimal operating cost	Will tend to favour lowest pumping rate solutions, with the same risks.
Shortest dewatering period	May be appropriate for emergency dewatering systems to recover a project after a failure or inundation, or for projects where the dewatering costs are small relative to project weekly on-costs
Maximum certainty of outcome	May be appropriate for projects where programme certainty is a key factor, and the dewatering must be fully effective without time consuming modifications.

7 CONCLUSION

There are a wide range of options for the design and implementation of dewatering systems. Designers will naturally be interested in strategies to optimise dewatering systems. Potential approaches to optimisation include: empirical (based on experience and rules of thumb); numerical/analytical (based on calculation and/or modelling); and observational (based on field measurements). In some cases, if a dewatering system is not effective it must be optimised in the field by a troubleshooting process, which may use a hybrid of optimisation methods.

It is important to realise that there is no perfect optimisation method that will address all the possible priorities for a dewatering system. In reality, different aspects of optimisation may conflict, and there will need to be trade offs between different priorities of design. For example, a dewatering system designed for minimum installation cost may not offer the least environmental impacts or the shortest period to achieve initial drawdown.

The required conditions for effective optimisation of dewatering systems include: clarity of the objectives of optimisation; adequate site investigation data; development of a valid hydrogeological conceptual model; and, selection of the most appropriate dewatering method at the earliest possible stage of optimisation.

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