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Numerical modelling of pressure reliefs in geotechnical problems

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ABSTRACT

This paper presents an investigation into finite element modelling of pressure reliefs in geotechnical projects. Two main topics to be discussed are relief wells used to reduce uplift pressures in excavations, and pressure reliefs which are used to minimize unwanted ground improvement installation effects. The key points to note are the different element types to model and not to model relief wells, and also that the performance of pressure reliefs is tied to the capacity of the wells. A case study of ground improvement works conducted adjacent to an excavation with pressure relief systems shows that the active relief system is able to negate soil movement due to installation effects.

Keywords: ground improvement; excavation; finite element method; pressure relief; relief well

1 INTRODUCTION

In deep excavation projects, it is likely that there will be large amounts of unbalanced water pressures. In such cases, tension piles, thick base slabs or drainage blankets may be used to negate the pressures. This paper will touch on the use of relief wells in such excavation projects.

Ground improvement techniques are necessary to stabilize soft soils to allow for safe excavation and construction. Specific methods such as deep soil mixing (DSM) or jet grouting have been successfully applied to many projects around the world in mitigating potential ground movements due to excavation works. However, the installation effects of these methods may work against the intended purpose. One way around this problem is to install pressure reliefs in the form of pressure relief wells within the vicinity of the ground improvement works.

This paper intends to present an investigation into finite modelling of ground improvement techniques coupled with artificial pressure reliefs. Further elaboration on the appropriate element types for relief modelling is also discussed. Numerical analyses were carried out using finite element code PLAXIS 2D 2018.0 and PLAXIS 3D 2017.1.

2 RELIEF WELLS IN GEOTECHNICAL PROJECTS

Relief wells are used in geotechnical projects to reduce porewater pressures in confined aquifers or stratified ground conditions. They are usually installed by augering or coring within a perforated steel casing, followed by filling with either sand or gravel. Geotextiles may also be wrapped at the base or around the well to prevent soil from entering the well. The casing may be installed by jacking into soft soil, or by coring through cement improved soil.

Most engineers tend to use 2D plane strain models for their excavation projects. While 2D models can be a good and efficient way to approximate the key behavior of geotechnical problems, care must be taken when using line drain elements as the performance of such elements may be too optimistic when compared to reality.

Generally, it is difficult to quantify the performance of relief wells in the field through analytical methods, due to interaction between complex arrays of wells, and excavation geometry. If done correctly, finite element methods can predict the influence zone and the effects of relief wells. The subsequent sections discuss the implication of various modelling techniques for relief wells in geotechnical projects.

2.1 Line element perfect drains

In finite element modelling, line drain elements are an internal boundary condition, where it allows the user to specify a head, where the pore pressure in all the nodes of the drain element will be reduced to the given head during groundwater calculations. If the surrounding soil has pore pressures below the specified head, it should not be affected by the drain element.

Drain elements are useful for modelling pre-fabricated vertical drains or empty perforated steel pipes used to drain water from behind the face of earth retaining structures. It is assumed that these drains are connected to the atmosphere, where the pressure head is zero, and there is almost no impedance to the flow.

In 2D analyses, a line element is equivalent to a trench or a plane in plane strain condition, or a hoop in axisymmetric condition where both of which are approximations of reality. Care must be taken when using such elements to model pressure reliefs.

Take for example a finite element model of a typical excavation project where the groundwater table is close to the surface, Figure 1. An interface element is modelled beneath the base slab to observe the active porewater pressures. Figure 2 shows the active pore pressures beneath a base slab at the steady state condition, without any pressure reliefs. When line drains are used, Figure 3, the pore pressures are significantly reduced, and even go into suction. This behavior is expected in the finite element model because there is a large differential water pressure between the ground surface and the excavated level, together with the presence of the line drain (where pore pressures must be zero). Thus, in order to achieve pressure equilibrium, the system at the base needs to be in suction. This phenomenon is unreal, and unachievable in a passive relief system without extracting water from the well.

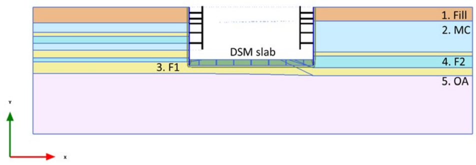

Fig. 1. 2D plane strain model of a typical excavation

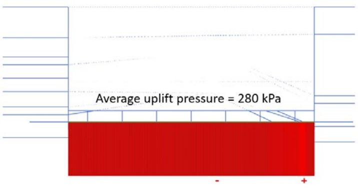

Fig. 2. Uplift pressures underneath the base slab

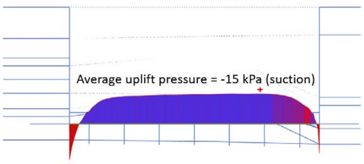

Fig. 3. Uplift pressures underneath the base slab with the use of line drain elements

2.2 Finite permeability drains

A more realistic representation of the performance of relief wells in excavation projects can be captured with the use of finite permeability drains. In other words, a soil cylinder with the physical dimensions and actual finite permeability is modelled for each well.

2D drains are modelled by smearing the permeability of the soil by its spacing in a plane strain model. Of course, a 3D model would be the best representation of the actual well, but for discussion purposes this section will touch on plane strain relief wells only. The same excavation from before is modelled with finite permeability drains in Figure 4. It is observed that the uplift pressure is reduced to a realistic value and does not go into suction.

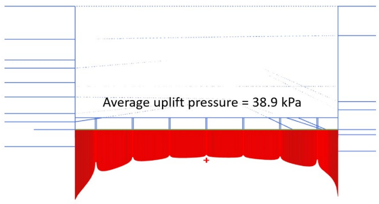

Fig. 4. Uplift pressures underneath the base slab with the use of finite permeability drains

Intuitively, the performance of relief wells should be a function of the permeability of the surrounding soil, and that the permeability of the well has a smaller influence. Some attempts were made to characterize the effects of difference in permeability of the drains, shown in Table 1. Finite element results show that the performance of relief well is dependent on the permeability of the ground, rather than the well itself.

If the permeability of the surrounding soil is low, then uplift pressures are also low, as suction is created upon excavating. Thus, there is no practical reason to have relief wells installed in soil with low permeability.

A comparison of the influence of different types of wells are shown in Figure 5 and Figure 6.

Table 1. Influence of permeability on uplift pressures

Permeability of drain (m/s)	Active pore pressures underneath base slab (kPa)
1E-4	38.9
1E-2	34.9
10	34.9

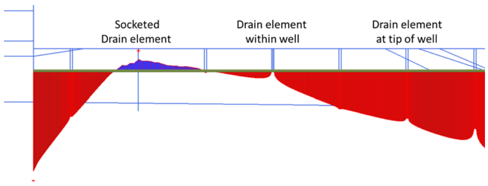

Fig. 5. Active pore pressures just beneath the base slab for different types of wells

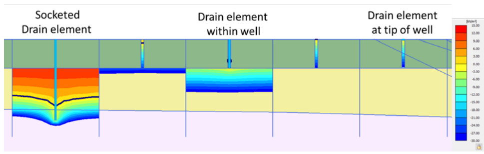

Fig. 6. Active pore pressures in the soil for different types of wells (Negative pore pressures are red to orange, positive pore pressures are yellow to blue)

3 MITIGATING GROUND MOVEMENT FROM GROUND IMPROVEMENT INSTALLATION

Ground improvement by means of cement mixing or injection is common in geotechnical projects to reduce ground movement. However, the installation effects may sometimes prove to be counter-productive to the intended design. Installation effects of ground improvement form a complex process where only the global behavior can be modelled. A few authors have discussed the installation effects of ground improvement, and the numerical modelling aspect of it. As much as 15% volumetric strain from jet grouting works was reported by Pinto et al. (2013), while Schweiger et al. (2004) reported compensation grouting volumetric strains from 0.25% to 1.5%, and Dong & Whittle (2017) reported volumetric strain of 0.5% for deep soil mixing works.

During installation of DSM columns, the expansive nature of the process resembles a cylindrical cavity shearing-expanding. The shearing forces generated by the rotating blades cause large amounts of excess pore pressures and clay fracturing within 2-3 times range of the column diameter (Shen, 2003). Thus, relief wells are critical to prevent damage to nearby structures. Meanwhile, the performance of relief wells can be put into two categories: passive relief wells and active relief wells.

3.1 Passive relief wells

A first cut modelling of relief wells can be done by assuming a passive relief well. Passive reliefs are modelled by replacing a column of soil with the actual dimensions of the well with a soft linear elastic material. The general idea of passive reliefs is that it is assumed that there is no removal of clay within the casing. In the finite element model, the amount of pressure relief is a function of the empty volume in the casing. Since there is no removal of clay within the well, the maximum capacity is quickly reached during the installation of DSM columns. This limits the capacity of the relief well in relieving pressures from the cavity expansion process.

Figure 7 shows two axisymmetric 2D models where a 1.75m diameter DSM column of around 30m depth is installed, with a 0.8m width relief well. The homogenous clay is represented by the Hardening Soil model. It can be seen that the relief well adequately negates soil movement, when the DSM is installed.

3.2 Active relief wells

In an active relief well, it is assumed that there is removal of clay within the relief well. Apart from using an elastic material to simulate the relief of pressure, negative volumetric strain is applied in the finite element model to simulate the removal of clay within the steel casing. The capacity of the relief well is actively restored over regular intervals through clay removal, leading to a more efficient pressure relief system. This method is a more accurate representation of actual site conditions.

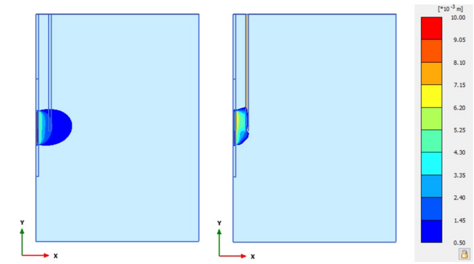

Fig. 7. Horizontal displacement contours of DSM expansion in the case without relief (left) and in the case with relief (right) in axisymmetric models

In finite element analyses, volumetric strain can be applied on soil polygons, where a positive value of the strain component represents an expansion, and a negative value represents a shrinkage in that direction. The expansion of the DSM column can be approximately modelled by a uniform positive volumetric strain, while the removal of clay within the relief well can be modelled by negative volumetric strain, as an approximate well response, that increases with depth, due to the increasing soil stiffness and pressure with depth. It should be noted that volumetric strains whether being fully applied or not depends on the stiffness of the surrounding soil clusters and objects, in order to maintain equilibrium.

3.3 Application of theory: A case study of ground improvement installation effects on a shaft

This section details a case study of a circular shaft in the reclaimed land of Singapore, that is within the influence zone of some DSM works, Figure 8. With reference to other projects in Singapore where similar thick soft clay was encountered, perforated steel pipes as relief wells were recommended, Figure 9. Both categories of reliefs were actively studied before concluding that active relief wells are more representative of actual site conditions, and that the mitigation scheme is feasible.

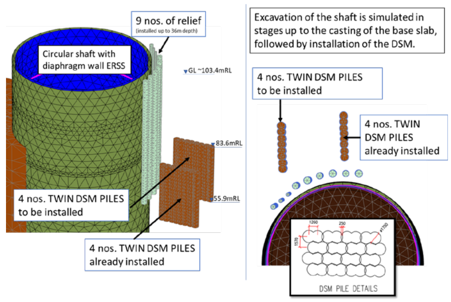

Fig. 8. Details of the shaft and ground improvement works

Perforated pipes are modelled in the ground to prevent the soft clay from pushing onto the existing structure during installation of the ground improvement. The relief system is able to work well as the clay is soft enough to flow into the perforations in the well casing and fall to the bottom of the well. Augering equipment is used to remove clay that has extruded into the well, which in a sense enabled an active relief system. In fact, if this system extracts too much soil, then the movement will be in the opposite direction; the excavation moves towards the reliefs instead of inwards to the excavation. To prevent this, proper ground monitoring, ground instrumentation and control is needed. The numerical model will be able to demonstrate this. Figure 10 shows a comparison of results when an active relief system was used as compared to when DSM was installed without any relief system.

Fig. 9. Perforated steel casing used as a pressure relief system

A trial with four twin columns being installed without reliefs was first carried out. Inclinometers around the shaft showed a maximum displacement inwards of about 2mm. After which, a decision was made to install a series of relief wells so that subsequent installation of DSM columns will have minimal impact on the shaft. Figure 11 shows the full layout of DSM works to be done, and Figure 12 shows the shaft displacement after that. It is very clear that the active relief system in both the numerical model and in reality, is able to mitigate the volumetric expansion effect on the existing structure.

4 CONCLUSION

This paper discussed on modelling relief wells in geotechnical projects. Care must be taken to use the appropriate element type, to avoid an overly optimistic prediction. When using a drain element to represent relief wells, all pore pressures within the line is negated. Instead of relieving pore pressures, the reverse problem is obtained where the soil goes into suction, an impossible feat in most soil filled drains. The performance of relief wells is more a function of the permeability of the surrounding soil rather than the permeability of the drain itself. Soil extraction which is simulated by volumetric control, must be modelled in order to capture the true behavior of the system.

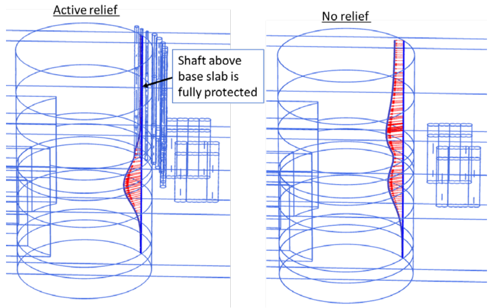

Fig. 10. Comparison of displacement contours of the shaft during DSM installation (vectors scaled 10000 times)

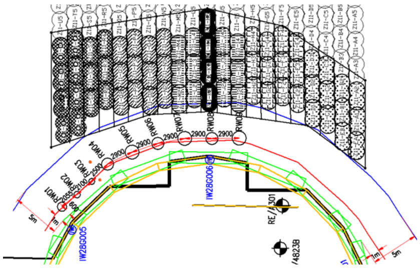

Fig. 11. DSM columns to be installed around the shaft

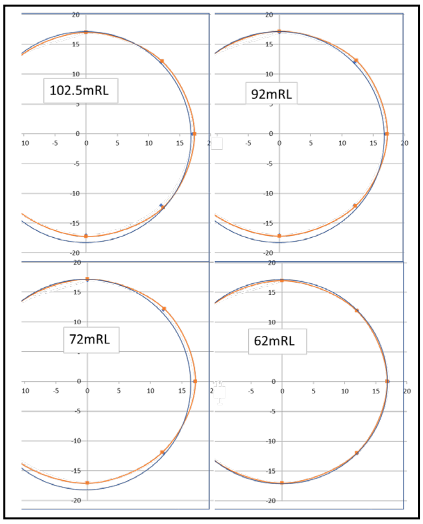

Fig. 12. Inclinometer readings around the shaft (DSM at the east)

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