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Reducing the effect of rising water table on the shallow foundation settlement using geopolymer resin injections

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ABSTRACT

The settlement of shallow foundations on granular soils is a critical factor in their design, and the rise of the water table due to seasonal or hydrological changes can lead to additional settlements, affecting the structural integrity of the asset. This paper investigates the use of expanding geopolymer resin injections as a cost-effective alternative solution to reduce foundation settlement due to a rising water table through numerical modeling. The study utilizes the PLAXIS software to run a series of virtual experiments, assessing the effect of geopolymer resin injections on foundation settlement with different rising water tables. The study found that geopolymer resin injections can reduce the impact of rising water tables on the settlement of shallow foundations and it is most effective when applied within the influence zone of the foundation.

INTRODUCTION

The settlement of shallow foundations on granular soils is a critical factor in their design. Settlement occurs due to the compression of the soil skeleton caused by the rearrangement of soil particles under foundation loads. The rise of the water table due to seasonal or hydrological changes can produce additional settlements of foundations resting on granular soils and can affect the structural integrity of the asset. The additional settlement due to the rise of the water table is mainly due to the reduction of effective stress, which in turn lead to a reduction in the shear strength of the soil, and also due to the water acting as a lubricant reducing particle interlocking and consequently reducing the soil modulus [1]. Accounting for the rise of the water in the design of shallow foundations can be difficult as it will require accurate prediction of water level changes, which is related to a multitude of factors that are hard to predict such as climate change and future hydrological changes. Therefore, in many instances when an unpredicted water table rise occurs, many foundations experience additional settlement which can lead to significant damage to assets. Retrofitting or protecting existing foundations from this phenomenon can be done via increasing the foundation size or resort to use of underpinning or in-situ piling, which can be time consuming and expensive. A potential cost-effective alternative solution is to use expanding resin injections. This technique involves injecting an expandable geopolymer resin into the ground to fill voids and compact the soil due to its expanding properties. Therefore, the aim of the study is to investigate the use of expanding geopolymer injections to reduce foundation settlement due to a rising water table via means of numerical modeling.

EFFECT OF WATER TABLE RISE ON FOUNDATIONS

The impact of a rising water table on shallow foundations is a critical consideration in geotechnical engineering. The rise of the water table can lead to additional settlements, which can threaten the integrity of the structure. The effect of the water table on foundation settlement has been studied by various researchers, and it is reflected in the value of the field standard penetration number (N). The soil stiffness is reduced when the soil gets saturated from a dry state, leading to a decrease in the intergranular shear resistance, due to the reduction in the effective stress, and an increase in slip potential. Terzaghi's hypothesis [2] that the soil modulus is reduced by 50% and the settlement is doubled in granular soils when the water table rises to the ground level, which is supported by some analytical studies and limited field data. However, it is not unanimously agreed upon the depth below which the rise in water table will have no effect on settlement. Generally, it is taken as one to two times the width of the footing below the base of the footing. The correction factor for the presence of the water table is used to multiply the settlement calculated in dry condition to obtain the settlement in submerged condition. Various researchers have proposed correction factors to quantify the additional settlement due to the water table rise below the footing.

The N value from the standard penetration test is widely used in many settlement prediction methods. The rise of the water table affects the N value, and various researchers have proposed equations for water table correction factors. A study by Bazaraa [3] studied the impact of the water table within the soil body and found that a rising water table would reduce the soil SPT N-values by 60% as shown in Equation 1, which would translate in an approximately similar reduction in soil modulus, which aligns with Terzaghi's hypothesis.

$$N' = 0.6N \qquad \text{(Eq. 1)}$$

Where:

N': is the soil SPT blow count in fully saturated conditions.

N: is the soil SPT blow count in dry conditions.

GEOPOLYMER RESIN INJECTIONS

Geopolymer resins are expandable resins that are injected into the ground for the purpose of void fill and soil stabilization via means of compaction grouting. When the geopolymer resin is injected in granular soil in a grid pattern, it creates expanding bulbs of geopolymer within the soil body with diameter between 0.2m to 0.6m, see Figure 1, which results in a compaction effect of the soil surrounding the bulb shown Figure 2.

Figure 1. Geopolymer bulbs injected into granular soil

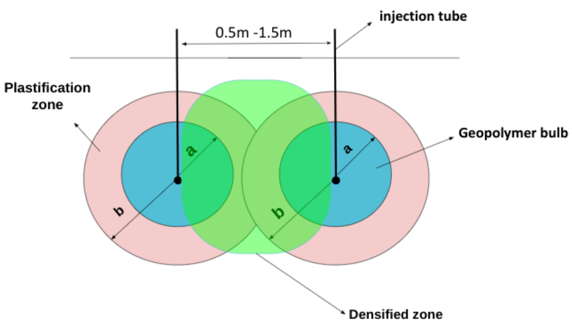

Figure 2. Theoretical illustration to soil compaction due to geopolymer bulbs

This phenom has been extensively studied by Dominijanni and Manassero [4] and derived a theoretical model to estimate the improvement in soil density due to geopolymer injection. The study theorized the the improvement in soil density due to geopolymer injections is a function of a few factors:

1. Quantity of geopolymer injected.

2. Type of geopolymer used in injections.

3. Grid spacing.

4. Soil initial density and angle of friction.

5. Overburden pressure.

Recent testing done by Geobear Global has shown that when injecting a relatively small quantity of geopolymer resin in a sandy soil, the SPT blow count can improve significantly. The testing involved injecting a highly expansive geopolymer in four locations in a 1m grid pattern at multiple injection depths (3m, 4m, 5m and 6) as shown in the injection layout in Figure 3. Figure 4 shows the N SPT blow counts per and after the injection. From the figure, it can be observed that following the injections the SPT blow count has improved on average by a factor of 1.7. It is important to note that the SPT testing was carried out in between the injection points as shown in the injection layout.

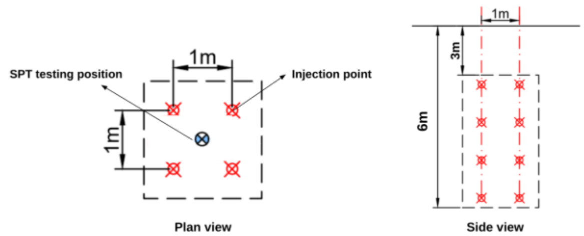

Figure 3. Test Injection layout

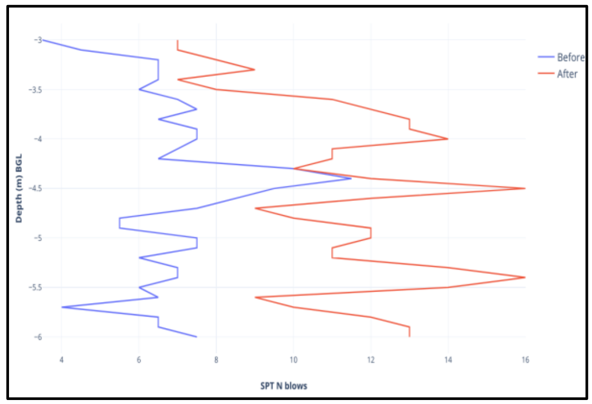

Figure 4. SPT blow count before and after injection

FE MODELLING

The aim of the study is to investigate the use of expanding geopolymer injections to reduce foundation settlement due to a rising water table via means of numerical modeling. The study utilizes PLAXIS software to run a series of virtual experiments to assess the effect of geopolymer resin injections on foundation settlement with different rising water tables.

The model consists of a typical concrete strip foundation with a width (B) of 1.5m an with line loading of 100kN/m. The foundation depth (D) is 1.5m below ground level and is resting on medium dense sand with an SPT N value of 12, see Figure 5. Several modeling scenarios were simulated to assess the foundation settlement with various levels of water table and resin treatment depth, as shown in Table 1. The material properties of the sand for each scenario were altered according to whether sand is dry or wet and whether it is treated with resin injections and summaries in Table 2. These properties were estimated using the following principles:

1. The SPT for the wet sand was estimated using the relation in Equation 1.

2. The soil modulus was estimated to be equal to double the SPT N value.

3. The improvement in the soil SPT blow count due to resin injections was estimated to be multiplying the SPT blow count by a factor of 1.7 (based on the findings of Figure 4).

4. The angle of friction was estimated using the SPT blow count and the relationship (12N^0.5+20) from [5].

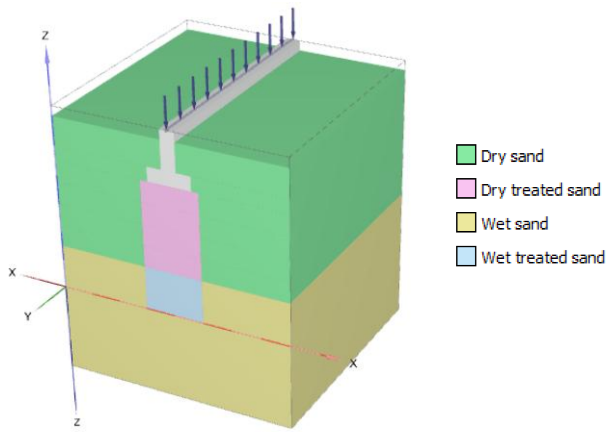

Figure 5. PLAXIS FE model

Table 1. Simulation scope

		Water depth below foundation underside (m)				
		4.5	3	2.25	1.5	0.75
Treatment depth below foundation underside (m)	No treatment	Scenario 1	Scenario 7	Scenario 13	Scenario 19	Scenario 25
	0.75	Scenario 2	Scenario 8	Scenario 14	Scenario 20	Scenario 26
	1.5	Scenario 3	Scenario 9	Scenario 15	Scenario 21	Scenario 27
	2.25	Scenario 4	Scenario 10	Scenario 16	Scenario 22	Scenario 28
	3	Scenario 5	Scenario 11	Scenario 17	Scenario 23	Scenario 29
	4.5	Scenario 6	Scenario 12	Scenario 18	Scenario 24	Scenario 30

Table 2. Model material properties

Material	**Model type**	**N SPT**	**Modulus (MPa)**	**Angle of Friction (deg)**
Concrete	Elastic	N/A	25000	N/A
Dry Sand	Mohr-Coulomb	12	24	32
Wet Sand	Mohr-Coulomb	7	14	29
Dry treated Sand	Mohr-Coulomb	20	41	36
Wet treated Sand	Mohr-Coulomb	12	24	32

RESULTS

The scenarios proposed in Table 1 were analyzed using the developed FE model and the results are shown in Figure 6. From the figure it can be observed that generally with the increase in the water table, the settlement increases and the maximum increase in foundation settlement tends to occur when the water table depth is within a depth equal to <2B. This is because most of the stress due to the foundation load is concentrated within this region hence the maximum impact due to the water table rise. On average the settlement increases by around 10% when the table rises by 1m across all scenarios. Also from the figure it can be observed that the modeled resin injection seems to reduce settlement, and the impact of the water table rises. When the water table is at 0.75 below foundation underside, the injection treatment reduces the settlement by approximately 17% and results in a settlement reading like the settlement resulting from a water table of 2.25m below the underside of the foundation - mitigating the impact of a water table rise of 1.5m. In addition to this, the injection treatment seems to be more efficient when applied within a depth between 1B to 2B.

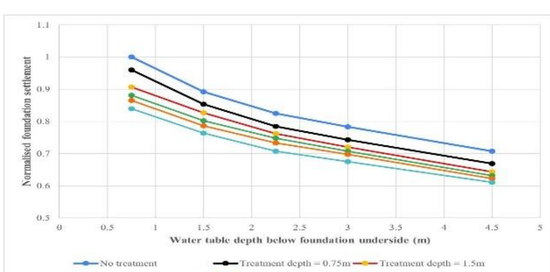

Figure 6. Foundation settlement because of different water table levels and treatment depths

CONCLUSION

In conclusion, the paper investigated the use of expanding geopolymer resin injections as a cost-effective alternative solution to reduce foundation settlement due to a rising water table through numerical modeling. The study shows that the modeled resin injection reduces settlement and mitigates the impact of water table rise. The injection treatment seems to be more efficient when applied within a depth between 1B to 2B. The paper provides valuable insights into the use of geopolymer resin injections as a potential solution to reduce foundation settlement due to a rising water table, which can be a significant problem in geotechnical engineering. The findings of the study can be useful for engineers and practitioners in the field to consider this technique as a viable option for retrofitting or protecting existing foundations from the impact of water table rise.

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