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THE USE OF EXPANSIVE GEOPOLYMERS TO MITIGATE FLOOR SLAB SETTLEMENT

By Dr Mohamed Wehbi, *PhD, CEng, FPWI*

Technical Director, Geobear Ltd.

mohamed.wehbi@geobear.com

Introduction

In the late 80's, engineers started to experiment with the use of geopolymer injections as a means to stabilise buildings' foundations suffering from subsidence. Since then, this technology has evolved significantly and became widely used in various construction industries. Geopolymer injections have been used, with great success, to lift and stabilise slabs in buildings, roads, airfields and railways. With 40 years of experience, Geobear (formerly known as URETEK) has been at the forefront with this technology and has developed various proprietary geopolymer types that allow for more optimised design solutions for various site problems.

This paper provides an overview about geopolymers as a sustainable engineering material that can provide cost-effective solutions to lift and stabilise heavily loaded slabs suffering from excessive settlement. Within the paper, a detailed case study for a commercial warehouse with a failing concrete slab was examined to illustrate how geopolymer injections have effectively stabilised the slab without affecting the operation of the warehouse.

Expansive geopolymers

Geopolymers are expandable resins that can be injected into the ground at high pressure using special injection equipment for the purpose of void filling and soil strengthening. Geopolymers have unique and excellent engineering properties compared to other conventional construction materials which make them ideal for sustainable construction, examples of these engineering properties are as follows:

Rapid hardening: unlike conventional grouting, geopolymers have a hardening time typically less than a minute, which means that the geopolymers benefits will be realised instantaneously. It should also be noted that depending on the geopolymer mixture, the hardening time can be varied to accommodate the requirements of different designs and applications.

Controlled expansion: depending on the Geopolymer type, Geopolymers can expand by up to 40 times their original volume and generate different lifting pressures. Highly reactive geopolymers tend to have a higher volumetric expansion and hence lower final density. On the other hand, geopolymers with low reactivity tend to have lower volumetric expansion and higher density. Understanding the intended application for the geopolymer is key to selecting the most appropriate type. For example for slab lifting applications, a geopolymer with high reactivity is preferred to achieve the desired lifts. On other hand, for ground strengthening applications, a geopolymer with low reactivity is preferred to achieve higher composite stiffness and strength.

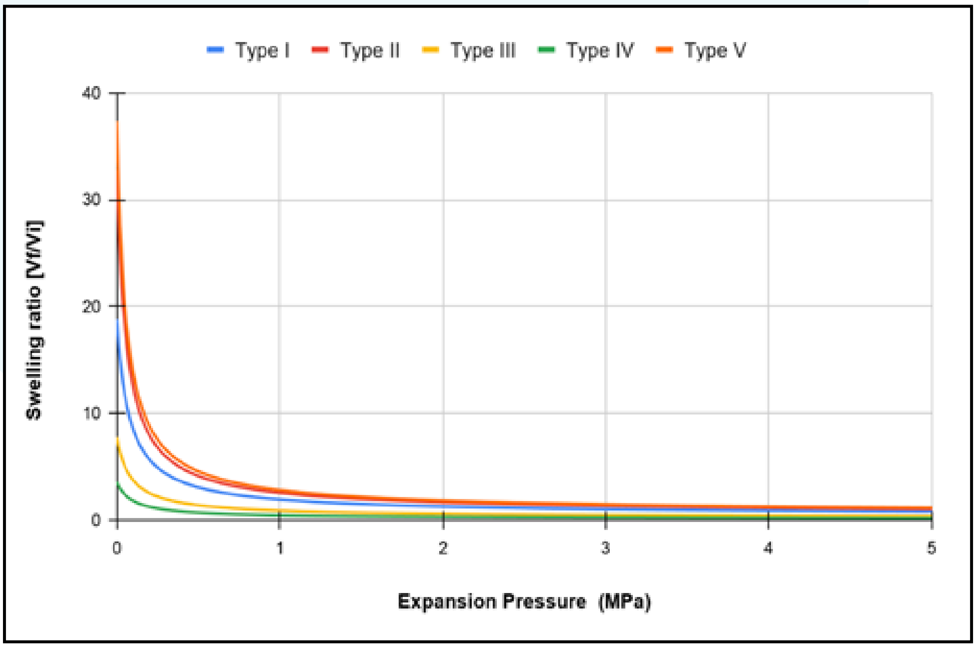
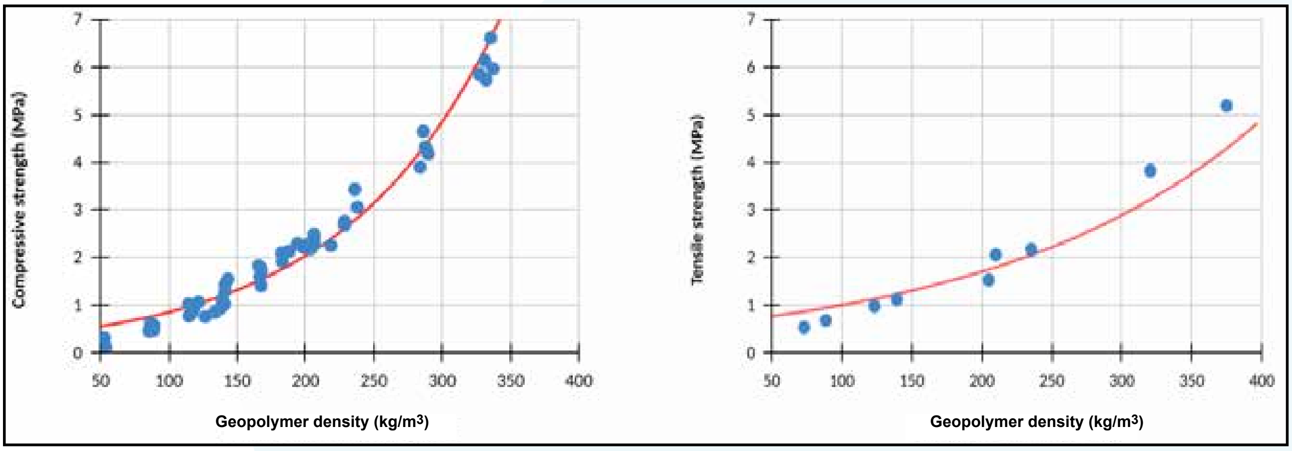


Figure 1: *Volumetric expansion for different types of geopolymers*

Lightweight material: Typically, geopolymers can have a final in-situ density that ranges between 150kg/m3 to 300kg/m3, which is almost 10 and 5 times lighter than typical concrete and grout, respectively.

High compressive and tensile strength: the unconfined compressive strength of the injected geopolymer varies with the in-situ density.. Higher geopolymer density will result in a higher compressive strength. Compressive testing was carried out by Padua University in Italy (Dominijanni and Manassero, 2014) has shown that there is an exponential relationship between the geopolymer density and the compressive strength where it can reach to up to 5MPa (see Figure 2a) for geopolymer density of 300kg/m3, which is 30 times higher than typical engineering fills. Unlike engineering fills, Geopolymers also have good tensile resistance, which is also dependent on resin density, and can reach up to 3MPa for geopolymer final in-situ density of 300kg/m3 (see Figure 2b).



(a) Compressive strength

(b) Tensile strength

Figure 2: *Padua laboratory testing results*

Controlled modulus of stiffness: according to laboratory testing done at the Padua University (Dominijanni and Manassero, 2014), the stiffness modulus of the geopolymer is dependent on the selected design density for the geopolymer where it can vary from 30MPa to 80MPa for geopolymer density between 150kg/m^3 and 300kg/m^3, see Figure 3.

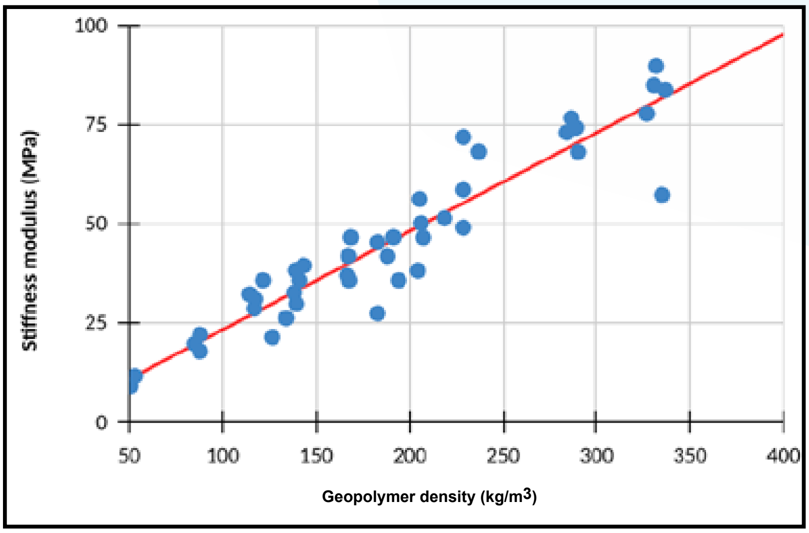


Figure 3: *The relationship between geopolymer density and modulus*

Water-free solution: geopolymers do not require water to initiate the curing and hardening process, and therefore they will not increase in water content in treated soils. In fact, the hardening in geopolymers occurs via an exothermic chemical reaction called polymerisation.

Environmentally friendly material: geopolymers' molecular structure is very stable and as a result they do not contaminate soils or water tables and are less susceptible to chemical attacks.

CASE STUDY: Europe's largest bottling plant & warehouse

The bottling warehouse is located just outside the City of Bristol in south western England. The warehouse is Europe's largest and has a total area of 81,000m^2 and was constructed in 2008. It is one of the biggest wine production and distribution facilities in Europe and has approximately 65 aisles with heavily loaded racks that exert a total ground bearing pressure of 30kPa (see Figure 4) via the floor slab. The slab was comprised of 250mm of fiber reinforced concrete supported with piles spaced at 3.3m grid.

Soon after the operation of the warehouse, the warehouse slabs started to experience signs of excessive

Figure 4: *Warehouse aisles and racks*

settlement, with up to 32mm in the worst location, which eventually resulted in significant cracking. The excessive settlement was creating an issue relating to the safe operation of the warehouse. It was estimated that the total affected area was approximately 25,000m^2 (26% of the total area). Following extensive ground investigations, it was believed that the principal reason for the excessive settlement was due to the presence of an 8m thick layer of very soft organic clay under the slab. Figure 5 shows borehole information along with the Standard Penetration Test (SPT) readings (which were derived from Cone Penetration testing) in one of the worst affected locations. The figure shows that there is a very soft clay layer with a thickness of approximately 8m under the slab foundation granular material with SPT values of less than 2. Furthermore, Triaxial Compression tests were also carried out to better quantify the clay strength, as shown in Figure 6. From the figure, the clay samples were found to have extremely low shear strength of approximately 7kPa in the worst affected locations. The heavy slab loading combined with the presence of ultra-low strength clay under the slab caused the clay to consolidate excessively leading to the observed high settlement levels.

To mitigate the excessive settlement in the warehouse, Geobear was commissioned in 2015 to use

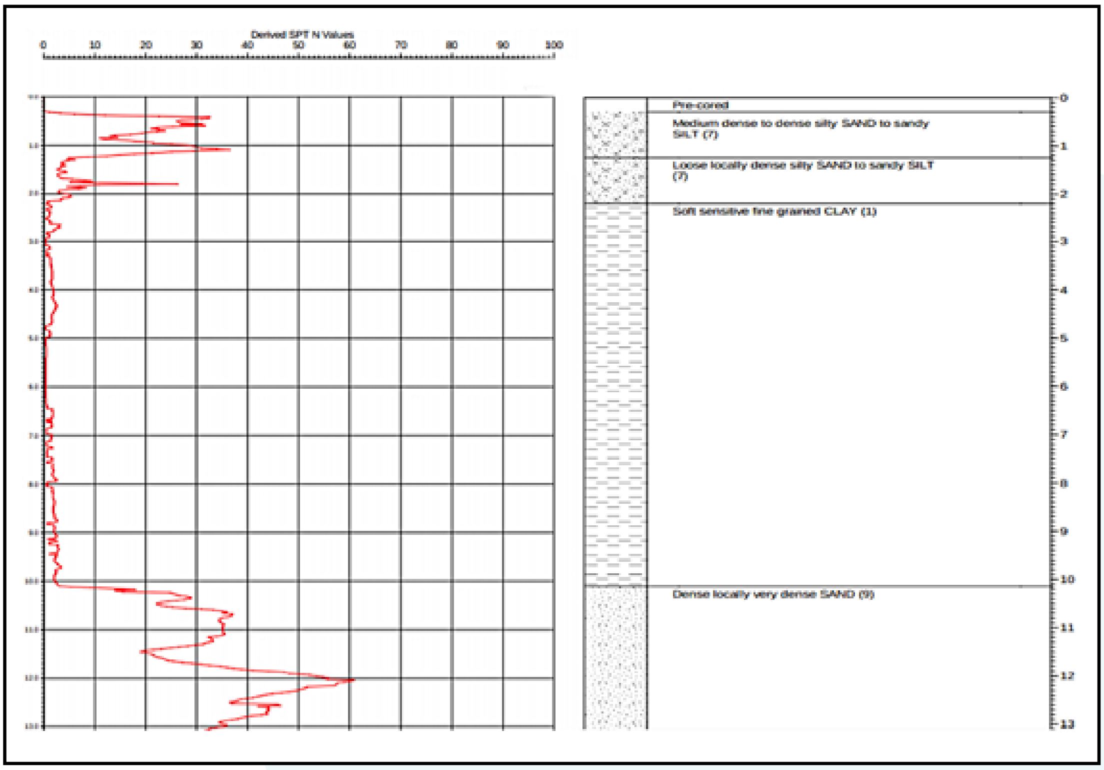


Figure 5: *Borehole information with derived SPT reading for one of the worse affected locations*

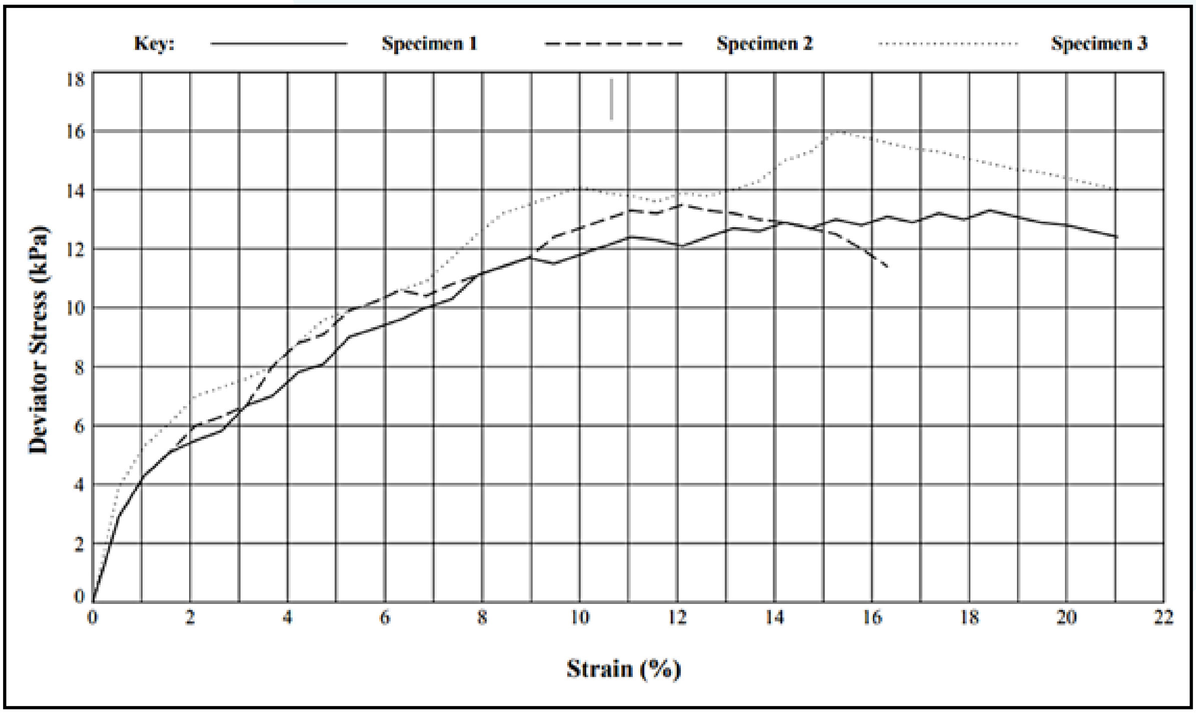


Figure 6: *Triaxial Compression test for clay specimens from one of the worst affected locations*

geopolymer injections to lift the slab to the desired level in accordance with FM-2 as defined in TR34 by the Concrete Society (The Concrete Society, 2016). Generally, the injection process consists of three main stages, as shown in Figure 7. The first stage involves drilling a 12mm diameter hole through the slab to the desired depth. Then, this is followed by inserting an injection tube to reach below the slab. The final and third stage involves injecting the appropriate amount and type of geopolymer below the slab. The injected geopolymer will expand below the slab and cause a lift action on the slab, as shown in Figure 8. During this process, the slab level is carefully monitored using laser levels to ensure that the desired lifts are achieved and are within tolerances.

Figure 7: *Stages of geopolymer injection*

Stage 1: Drilling

Stage 2: Insert tubes

Stage 3: Inject and monitor

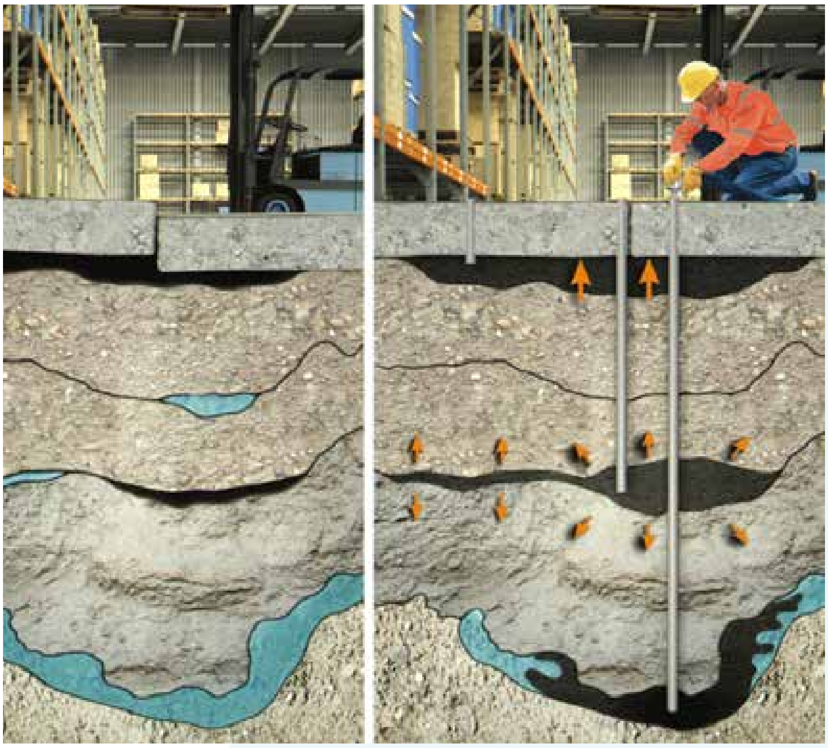
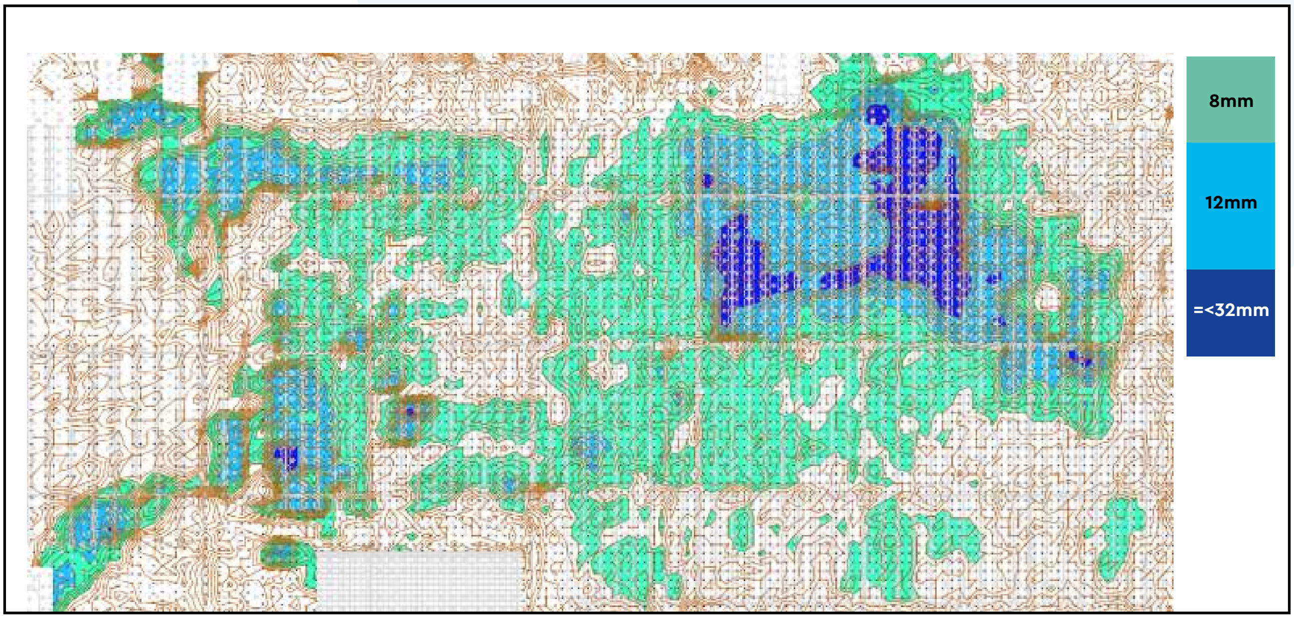


***Figure 8**. Geopolymer lifting action*

For the warehouse, the slab lifting was carried out in three passes and they were mapped on the warehouse layout as shown in Figure 9. Three passes were undertaken to minimise stresses within the slab and ensure tolerances are maintained. These passes were assigned according to the experienced settlement in each area and were as follows:

- One lifting pass was carried out to lift areas that experienced settlements of up to 8mm.
- Two lifting passes were carried out to lift areas that experienced settlements between 8mm and 20mm.
- Three lifting passes were carried out to lift areas that experienced settlements between 20mm and 32mm.

***Figure 9**. Mapped lifting passes on warehouse layout*



During each pass, the slab lifting was carried out in multiple small increments until the target level was achieved and with a tolerance of -1/+3 mm. A further phase of treatment was also carried out to re-adjust the slope gradients that are out of tolerance and achieve a flatness gradient target of 1:500.

The lifting works took place in two aisles at a time, while they were fully loaded, and after the completion the aisles were handed back and a possession of the next two aisles was followed. The work was completed in a period of 16 weeks without affecting the operation of the warehouse and the lifting levels were verified by a third party surveying team. It is important to note that the use of the geopolymer injection technology provided a cost-effective solution to mitigate the excessive settlements of the warehouse slabs. The conventional alternative would have been to carry out major reconstruction to the slabs, which would have cost the asset owner a sizable sum along with severe disturbance to the operation of the warehouse.

Conclusion

The aim of this paper was to introduce geopolymer injection technology as a cost-effective solution to re-stabilise slabs with excessive settlements. This was supported via a case study, Europe's largest bottling plant & warehouse, which highlighted the procedures involved when using this technology and its effectiveness in real life applications. Having this said, the following can be concluded from this paper:

- Geopolymers have excellent engineering properties, which allow them to be an effective and sustainable construction material.
- Appropriate site investigation is essential to identify the underlying problem so a suitable geopolymer treatment can be selected and applied.
- Careful planning and post validation measurements are crucial to fully realise the benefits of geopolymer injections.
- Geoplymer technology can provide cost-effective solutions to difficult problems post construction.

References

Dominijanni, A, and M Manassero. Consolidation of soils with expanding resins design guide. Milan: McGraw-Hill Education, 2014.

The Concrete Society, 2016. TR 34: Concrete Industrial Ground Floors. [online] Exeter: Short Run Press Ltd. Available at: <http://freeit.free.fr/Pour%20Pierre/TR34%20-%20Concrete%20Industrial%20Grou%20-%20Concrete%20Society%20Working%20Party.pdf> [Accessed 16 June 2021].

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www.geobear.co.uk 0203 773 4866
Mere One, Mere Grange, Elton Head Road, St Helens, WA9 5GG