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Anchor Jet the ultimate anchoring solution?

Large diameter grout bulb extractible ground anchors in soft clays: a case study in Geneva

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ABSTRACT The Geneva Skylab project required the construction of a 12 m deep basement in saturated soft clays in an urban environment. The initial concept design included internal bracing of the excavation by props. An alternative anchored solution was developed, applying Forasol's patented Anchor-Jet® large diameter bulb ground anchors, which allowed to remove almost all struts in the basement box. Due to local regulations, ground anchor free lengths had to be extracted after use. This paper evaluates the implementation of Anchor-Jet® ground anchors for the Geneva Skylab project, identifies key issues with this type of anchor, and provides suggestions of further study to deepen understanding of the technology.

1 INTRODUCTION

As part of the Geneva Skylab development, it was proposed to construct a 3 storey basement (plan dimensions 130 x 65 m, up to 12 m below ground level). Given ground and site conditions and previous experience in the area, an anchored retaining wall was deemed unsuitable at concept stage, and bracing was to be carried out by 3 levels of props crossing the site (GADZ 2011).

With main contractor Induni & Cie. SA and specialist geotechnical contractor Forasol SA, BG Consulting Engineers value engineered the basement design to remove most props and free up space in the excavation. This was achieved thanks to Anchor-Jet®, a patented Forasol technique (European Patent EP 1 087 063 B1) which creates a strand anchor with a jet-grouted bulb. By substantially increasing the effective bulb diameter compared with traditional injected anchors in soft clay, excellent prestress capacity was achieved in the ground anchors and the basement was delivered successfully.

The aim of this paper is to provide a case study of the application of Anchor-Jet® for the Geneva Skylab project.

2 GROUND CONDITIONS

The Geneva Skylab project is located in Plan-les-Ouates, to the South of Geneva. Local ground conditions comprise 30-40 m thickness of glacial retreat deposits, from the last Alpine (or Würm) glaciation. In the area of the site, this formation is composed mainly of saturated, soft, normally consolidated, medium plasticity clay, classified 6e2 according to the Geneva geological classification system (described in Fontana 1973). Cemented sand and gravels ("alluvion ancienne" formation, classification 9a), with an artesian groundwater level, can be found at depth.

Site ground conditions were determined based on the following information:

- The investigation for the original project conducted in 1988 by consultants Amsler, comprising 10 rotary cored boreholes to a depth of 15 m on the Skylab site, in situ (SPT) and laboratory testing (soil identification and oedometer tests);
- Ground investigation conducted in 2008 by consultants GADZ for the neighbouring Blue Box project, comprising 12 trial pits;
- Borehole logs from surrounding developments, with depths in excess of 30 m, which are available in the Geneva geological database.
- 5 trial pits carried out on the Skylab site in 2012 (Figure 1).

Figure 1: trial pit spoil heap demonstrates soil cohesion and softness

Based on the above information, GADZ produced an interpretative report and a conceptual ground model, compiling existing geotechnical data and giving recommendations and design parameters for the Skylab site (GADZ 2011).

Key geotechnical parameters for the clay formation are summarised in Table 1.

Table 1: Geotechnical parameters for clay layer (GADZ 2011)

Parameter	Symbol	Value	Unit
Unit weight	γ	19.5	kN/m^3
Undrained shear strength	c_u	40	kPa
Angle of shearing resistance	Φ'	25	°
Effective cohesion	c'	8	kPa
Drained Young's Modulus	E'	5 000	kPa

3 SKYLAB PROJECT SUMMARY

The Geneva Skylab project began as a brownfield site redevelopment design competition won by architects BassiCarella Architectes and BG Consulting Engineers in 2011. The concept comprised a 6 storey building with 3 basement levels, to house 500 car parking spaces.

In the geotechnical interpretative report (GADZ 2011), basement strutting by ground anchors was deemed unfeasible, due to low skin friction in the clays and serious creep issues with ground anchors on an adjacent site. As a result, tender design included bracing of the excavation exclusively by crossing struts.

Once the construction contract had been awarded, design development was carried out by main contractor Induni, together with BG Consulting Engineers, with the aim of reducing conflicts between bracing and concreting in the basement box and optimising the construction programme.

The key to reducing clutter and speeding up construction was to replace most of the bracing by using anchors. However, for anchors to be deemed feasible, the following conditions would have to be met:

- Anchors had to be strand anchors (bars too stiff);
- A prestress capacity of up to 600 kN would need to be achieved, to ensure sufficient spacing between anchors;
- Anchor free length would have to be extracted after use, as all elements left in the ground after use are taxed by the local government (Législation genevoise L1 10.15 1988).

Specialist geotechnical contractor Forasol proposed to implement its proprietary Anchor-Jet® technology in its tender for the Skylab project in order to meet the above requirements.

4 ANCHOR-JET®

Anchor-Jet® is an anchoring technique which drives a modified strand anchor into the ground, and creates a cement bulb by jet grouting as the probe is retracted. Grout pressures of up to 500 bar can be achieved. The construction sequence is given in Figure 2.

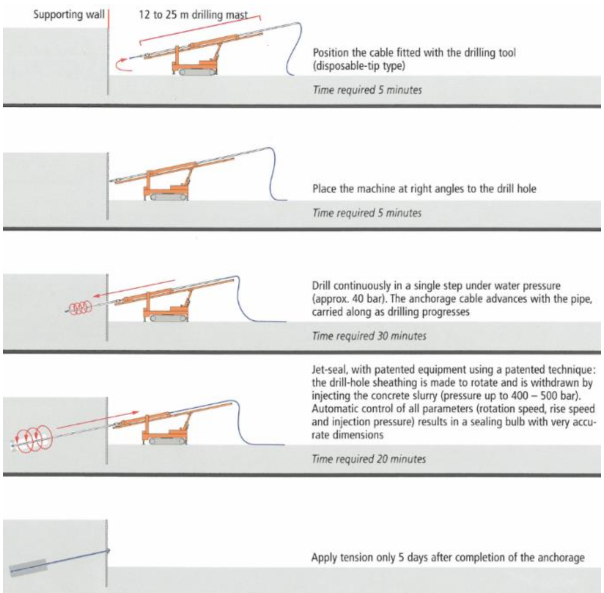

Figure 2: construction sequence of an Anchor-Jet® anchor (image: Forasol SA)

Forasol uses a customised drilling rig to install these anchors. Rig dimensions are given in Figure 3 and key data are given in Table 2.

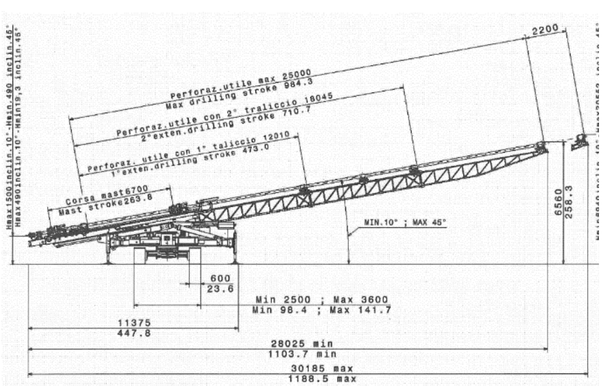

Figure 3: rig dimensions (image: Forasol SA)

Table 2: key rig data (source: Forasol SA)

Rig base model	EGT VD 7800
Rig weight	36 t
Anchor angle	10° to 45°
Max drilling length	25 m
Max production rate	200 m / day

Ground anchors used for Anchor-Jet® are modified strand anchors (Stahlton or similar): anchors are delivered to site with no tube-à-manchette, and a point is welded to the end of the anchor, to help with the drive (Figure 4).

Figure 4: customised anchor points

5 ANCHOR TESTING

5.1 Preliminary design assumption

Preliminary Anchor-Jet® design was carried out according to the Bustamente method (Recommandations TA-95), which suggests typical values of skin friction (q_s) for standard anchors as a function of CPT and SPT values, depending on whether soil is granular or cohesive. A preliminary value of q_s of the order of 60 kPa for the grout bulbs in the clay formation was determined.

5.2 Off-site approval testing

During the value-engineering phase, Forasol made available a report (Forasol 2012) describing test results from 3 Anchor-Jet® trial anchors carried out in the same clay formation close to the Skylab project, which demonstrated q_s values of 65 kPa. Ground conditions at the test site were considered very similar to those at Skylab. These results importantly demonstrated the technical feasibility and satisfactory behaviour of Anchor-Jet® in this clay formation.

5.3 On-site pull-out tests

Ground anchors according to Swiss Standards (SIA 267) are designed based on pull-out tests. Three tests were carried out on the Skylab site, with bond lengths of 4, 5 and 6 m respectively.

The aim of this test is to pull the bulb to failure. The load at which creep (rate of bulb displacement, labelled k) is becomes critical is defined as the ultimate resistance. Ultimate skin friction is then back-analysed from this.

Figure 5 illustrates the result from pull-out test n°2. The test anchor was loaded at 100 kN increments (P1 to P5), starting at 200 kN, until creep observed became critical (k_{crit} = 2mm, as defined in SIA 267). Anchor failure was observed at P5 = 600 kN.

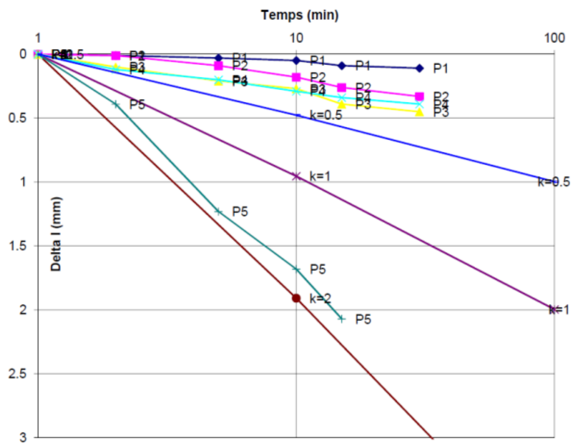

Figure 5: Pull-out test n°2 (bond length 5 m), P1 = 200 kN, increment 100 kN, P_{creep} = 600 kN

A minimum skin friction q_s of 68 kPa was determined for the Skylab site by carrying out a back-analysis of the pull-out tests, and anchor design was verified.

5.4 Testing production anchors

In accordance with Swiss standards (SIA 267), every production anchor tensioning was measured and a record sheet produced for the Skylab project. In addition, 10% of production anchors underwent extended testing, which included tensioning in three steps. The aim was to verify whether production anchors were behaving like the test anchors, and check whether effective free length and bond length were in conformance with the design.

All production anchor reports were checked by the resident engineer on site. Anchor-Jet® effective free lengths were found to be especially conformant with theoretical lengths, due to the fully automated jetting process.

6 PRODUCTION ANCHORS

Geotechnical works began on site in April 2013, and the final ground anchor was extracted in April 2014. Key data regarding anchor production is summarised in Table 3.

Table 3: key anchor production data

N° of production anchors	500 no.
Daily rate	10 no. /day (150 m/day)
Grout bulb diameter	60 cm
Bond length	4 m to 6 m
Free length	7 m to 11 m
Prestress	400 kN to 600 kN

A number of site issues required to be resolved at the start of anchor production:

- Ground swelling was observed above the bulb location of the test anchors. The reason for this phenomenon was poor spoil removal during drilling of the first anchors, caused by progressive closing of the drill hole. This was resolved by systematically applying a pre-washing drive before installing the anchor and beginning the grouting phase.

- Pre-washing and jet grouting generate large volumes of spoil, which ruins working platforms and can impact adjacent works (excavation and concrete works). Effective spoil management solutions had to be designed (Figure 6).

Figure 6: effective spoil management (storage bund and pump truck)

Once these issues were resolved, anchor production was quickly ramped up and daily rates were relatively consistent.

7 GROUND ANCHOR MONITORING

The retaining wall around the site was monitored for the duration of its design life. Monitoring put in place is summarised in Table 4.

Table 4: Skylab retaining wall monitoring

Instrumented sections	7 no.
Inclinometers	7 no. (length 25 m)
Survey points	22 no.
Load cells on anchors	20 no.

The evolution of anchor prestress load with time was observed on a weekly basis, and cross-checked with inclinometer and survey point data, to ensure overall stability of the retaining walls and resistance of the ground anchors for the duration of construction.

Prestress load was plotted as a function of time, as shown on Figure 7. It was found in general that loss of prestress was typically of the order of 10%, over the first 6 weeks, followed by a stabilisation period. The maximum design life of a ground anchor on the Skylab project was approximately 6 months.

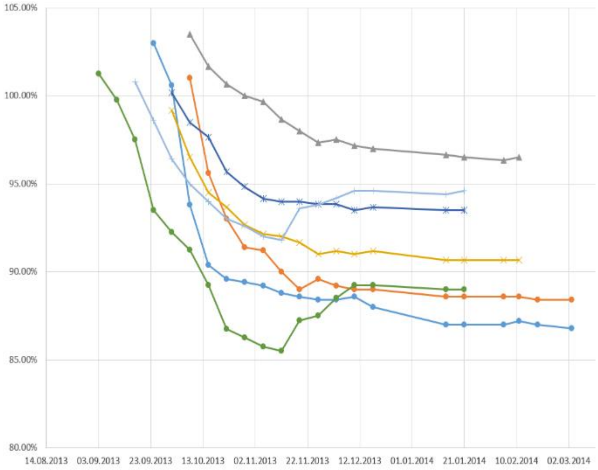

Figure 7: Anchor-Jet® load evolution with time

8 ANCHOR EXTRACTION AFTER USE

One of the prerequisite conditions for adopting Anchor-Jet® on the Skylab project was that anchor free lengths would have to be removed after the anchors had been unloaded.

Free lengths are removed by jacking individual strands, until a yield point is generated (Figure 8). The yield point must be situated at the interface between the free length and the bond length.

Figure 8: anchor free length extraction

This yield point can be predefined by generating a mechanical weakness at the required interface. The solution proposed by Forasol involved inserting a thermal probe up to the interface and heating the strands. The evolution of strand strength with temperature is given in Figure 9. Once sufficiently heated, the strands are individually jacked out.

A successful extraction rate of 91% was achieved on the Skylab project. By comparison, an extraction rate of 85% is considered acceptable according to industry standards (ASEP March 2010). Reasons for failed extractions are multiple, but in the case of Skylab can often be attributed to damage caused to strand free lengths during subsequent excavation and concrete works.

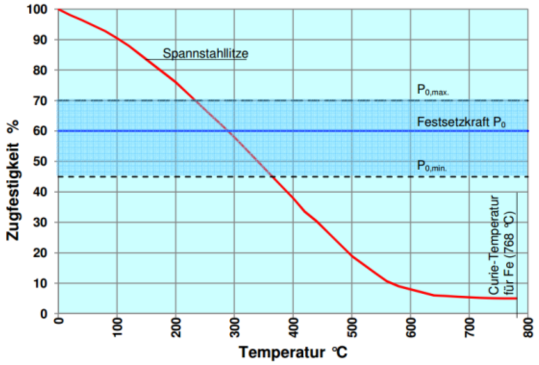

Figure 9: Evolution of strand strength (% of nominal strength) with temperature (source: Stahlton AG)

9 CONCLUSIONS

The advantage of Anchor-Jet® lies in the extra large diameter of the grout bulb which can be formed. With this technique, strand anchor capacity in poor soils can be greatly enhanced in comparison with traditional reinjected ground anchors. In the case of the Geneva Skylab project, anchors once again became a feasible option.

The following advantages with Anchor-Jet® were observed on the Geneva Skylab project:

- Excellent anchor performance in soft clay;
- The fully automated jetting phase allowed for excellent bond length control;
- Fast technique compared with traditional anchors (no secondary injections required, 5 days from jetting to stressing).

The following points may require to be considered when evaluating inclusion of Anchor-Jet® in a project:

- Site installation is large in comparison with a traditional anchor batching plant, and requires easy access by a silo truck;
- The Anchor-Jet® rig has a long mast, which requires excellent site coordination;
- Like all jetting techniques, Anchor-Jet® generates large volumes of spoil. Spoil needs to be well managed on site and disposal effectively costed in estimates.
- Jetting can cause ground swell if spoil evacuation is poorly managed. Good spoil flow must be ensured at all times.

10 FURTHER STUDY

To date, all Anchor-Jet® ground anchors have been implemented for temporary works. There is no available information on the long-term performance of these anchors under stress.

As recommended in BS 8081 § 6.2.2.6, additional tests should be undertaken to evaluate whether this technology can be extended to permanent applications.

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