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# Pre-treatment to enable excavation within saturated non-cohesive soils to facilitate multi level basement underpinning

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ABSTRACT:
*The ability to stabilise a variety of non-cohesive soils has great utility in ground engineering work. Where underpins are to be formed to whole structures in running soils, the need to provide solidity and a waterproof barrier at the same time is required. This can be achieved only through highly accurate and reliable placement of suitable solidifying materials. With growing demand for the construction of deeper basements and other underground structures in problematical soils, innovative soil pre-treatments can provide engineers with the necessary tools to carry out hitherto highly demanding phases of underpinning work, with greater confidence.*

INTRODUCTION:
Those familiar with the problems of excavating through non-cohesive saturated soils below the water table will appreciate that preventing the running-in of particles during excavation is a major challenge to the contractor. With the continuing wave of investment into London real estate and the sustained increase in property values, the preferred solution for investment clients and owner/occupiers is the formation of deep basements under existing high value properties. This introduces a range of practical difficulties at the construction phase. One common problem is how to construct a basement below the water table in non-cohesive deposits such as River Terrace Gravels. The development of a reliable method of stabilising non-cohesive soils in difficult to access locations has become urgent. In this case study, we discuss a high value and high demand project in London's Knightsbridge district.

The subject of this study is a terraced period residence in Ennismore Gardens SW7 with a market value well in excess of £24m. The recent trend to increase the living space and thereby enhance the value of the property is to construct new basements or increase the number of levels beneath existing basements.

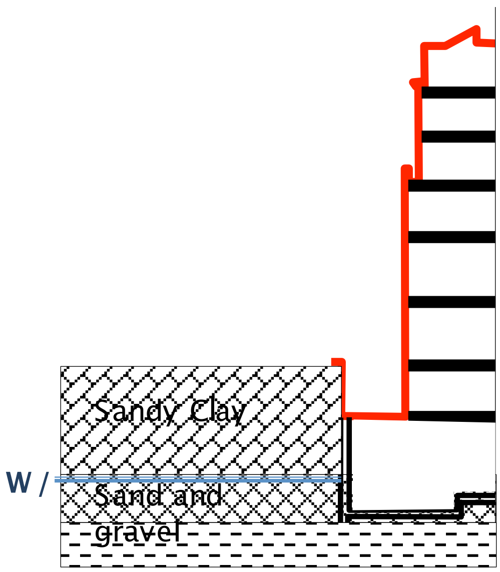
Those properties founded directly on London Clay or those well above water table level can be dealt with using conventional underpinning and shoring techniques. However, within much of the high value areas of London, the clay can be overlain by a range of granular alluvial deposits ranging from cobbles to silt. Where these soils are below water table level the problem with excavation becomes severe and often the confined nature of the site imposes such restrictions as to prevent the use of large plant or equipment. New solutions are required.

Number 4 Ennismore Gardens is a substantial Victorian Terrace (c. 1870) arranged over six above ground level floors and originally with one basement level. The development is within the Knightsbridge Conservation Area and has a notable limestone clad front elevation.

GEOLOGY: The geology of the site, from a single borehole, comprised made ground with topsoil and builders rubble to 0.8m below ground level (BGL) then firm becoming stiff sandy silty clay becoming more sandy and coarser with depth. At 5.5m BGL was a transition to sand becoming gravel at 6.3m BGL and then coarse gravel with clay and silt inclusions. Stiff brown clay was encountered at 7.1m BGL.

Water level was approximately 4.6m BGL within the sands and gravels. Subsequent boreholes from constructed basement 2 level revealed that the terrace deposits depths varied considerably and the interface between the sands and gravels and clay was uneven. In general the London Clay was encountered at greater depth towards the rear of the basement.

THE DEVELOPMENT:
The development project at 4 Ennismore Gardens included deepening the basement under the whole of the property to accommodate a swimming pool, plant room and associated leisure facilities. The formation of this new area required excavation beneath the existing basement of up to a further seven metres approximately. This was achieved in two phases, the first, being the formation of conventional 1.2m wide 3.7m deep reinforced concrete underpins within the clay down to near water table level. The architect’s design called for the deep end of the pool to be located to the rear of the basement (see section). The required formation level being approximately at the top of the London Clay, therefore excavation down through the water bearing Terrace River Deposits was necessary. The presence of saturated, non-cohesive soils complicated the construction sequence considerably because it would now be necessary to consolidate the material behind the construction line of the underpins so that concrete could be placed directly below the termination of the upper underpin section. In addition, the whole of the perimeter affected by the sands and gravels below water table needed to be treated so that a virtually dry box was formed, in which excavation could be carried out, without risk to the main property or the neighbouring ones. Put simply, the pre-treatment permeation grouting had to form a virtually waterproof barrier.




SITE CONSTRAINTS: Access into the basements of terraced properties is always a key consideration and Ennismore Gardens is no exception. The access to the site was limited to the front main entrance door and occasionally the front light well. No large plant could be used. This severely limited the choices of methodology for ground stabilisation to a system which used highly portable equipment and easily handled materials.

GEOTECHNICAL SPECIALISTS:
Geotechnical and Basement contractor Abbey Pynford contacted Slough and Hong Kong based specialist Stress to look into the possibility of using their unique permeation system as a potential method of stabilising the non-cohesive water bearing deposits below the site. Stress had been using a polyurethane permeation grouting system called ReFORCE* for a considerable time and had gained a great deal of experience in reliably and accurately placing Normet’s GeoTek LV** polyurethane grout into the ground using GeoInnovation’s unique patented lance system.

ReFORCE SYSTEM:
The advantage of the ReFORCE system is that it allowed a very high degree of control over the exact locations and the quantity of grout introduced into the ground at pre-determined positions. In this way, Stress was able to create a continuous linear mass formed from overlapping lobes of permeation grouted ground. The need for a very high degree of integrity was paramount to ensure stability for excavation and to prevent water ingress and the potential resultant loss of soil from beneath the neighbouring foundations.

The following diagrams show the sequence of permeation and construction of the RC pool walls.

SEQUENCE OF WORK: (with reference to the sketches 1 to 5)

The sequence of work can be seen with reference to the schematic drawings. The original construction comprised a basement containing mainly old servants working areas. At the rear of the property was a patio garden enclosed by a retaining wall. The first sequence of work was to cut away the inside of the corbeled foundation (1) and form the upper underpins to just above water table level. The upper underpins were formed with a toe, this was a temporary feature and served to provide an adequate spread footing to support the structure above. It also contained continuity reinforcement for connecting into the next level of underpin (2). The floor was blinded with plain concrete. With non-cohesive soils extending from the upper underpin section to the top of the London clay over much of the basement area, pre-treatment consolidation was required to facilitate the formation of the lower underpins.

The pre-treatment (3) zone had to extend beyond the back face of the lower underpins to allow for a sufficiency of consolidated material to enable safe excavation. Stress accurately placed a continuous pre-treated barrier between the underside of the upper underpin and the undulating and unpredictable surface of the London Clay.

With the whole perimeter of the pre-treatment completed, de-watering could commence. Drawing down the water was carried out over several days as water had to drain from approximately 150$m^3$ of sands and gravels. To speed up the de-watering process, a number of wells were formed in strategic locations. As the rate of extraction reduced to a few litres per minute the underpin pits could be excavated (4). Part of the excavation process required trimming back the pre-treated ground to form the required mould for the underpin. During this process Stress provided a technician on standby to control any minor leakage which occurred. The positioning and integrity of the pre-treated ground was such that no weak or under thickness zones were exposed.

The lower section of underpinning proceeded smoothly in accordance with the programme for the works (5) and was brought to a successful conclusion.

The requirement for a reasonable level of water tightness was achieved; however, it was never expected to be 100% waterproof at the initial stage. Small leakages were considered probable in the scheme. Stress had a well-developed and planned contingency to deal with any minor ingress, this was carried out in conjunction with the underpinning work as the pits were excavated. It was interesting to note that the volume of water ingress was very small, amounting to one or two litres per minute. Dealing with small leaks at isolated locations proved uncomplicated and reliable.

CONCLUSION:

With greater numbers of older properties being extended into ever deeper basements, the difficulty of overcoming the problem of running sands and gravels in extremely inaccessible locations is becoming more common. The ReFORCE Pre-treatment system has proved that a virtually waterproof and physically strong structure can be accurately formed beyond the outside of the building line to enable the optimum placement of concrete underpins.

Once the whole of the pre-treatment had been carried out, the sands and gravels within the pre-treated area could be de-watered. It was then possible to shore and excavate against the pre-treated ground directly below the upper underpin. The pre-treated ground was found to be robustly solid and required mechanical breakers to remove it. However, this made it possible to cut out an accurate profile for the wall, toe and base of the basement box.

* ReFORCE Lances are a new economic and valuable tool, which have been developed within the underpinning sector of the geotechnical industry. These patented lances can be driven accurately to considerable depths and permit suitable resin grout to be delivered precisely both in location and quantity. A ‘Driven-in’ system has the advantage of being unaffected by running sands or other collapsing soils which would affect a drilled system, in addition, requires only small portable plant to

be used.  The ReFORCE Lances are sacrificial and remain in-situ, this permits closely spaced grout lobes to be formed which overlap, essential where barriers are to be formed or loads carried.  Such overlaps would bind in or prevent the insertion of re-usable or withdrawn lance systems.  Vertical grout dispersion is accurately controlled by delivering specified quantities of grout at intervals along the length of the lance.

**GEOTEK LV:     To improve reliability of the application, Stress used GeoTek LV polyurethane.  This low viscosity geotechnical product has been specifically developed for permeation grouting  by Normet and therefore has exceptional penetrative properties.  The LV grout does not behave in the same way as a simple Newtonian fluid.  The product's low viscosity allows exceptionally good permeation into non-cohesive soils at low pressure.  As the polyurethane passes through damp or saturated soils the water reacts with the product to form CO2 micro-bubbles which both reduce viscosity and boost permeation.  Because the inflation phase occurs within the whole permeated mass over a protracted period, better than average and more predictable consolidated lobes are formed.  This allows for more accurate control over the volume and shape of the mass within variable horizons of soil when compared with simple Newtonian fluids, which tend favour the path of least resistance to a much greater extent.  The resultant consolidated mass has a characteristic strength in excess of $5N/mm^2$ whether formed under or above the water table.

The illustration above shows the reinforcement cage (D) installed into the recess formed below the underpin (A) and next to full depth underpin (E).  Concrete (C) is the old underpin toe, which has been broken back approximately to the required line.  Lance tubes (B) can be seen in-situ.  W/L is the approximate water level outside the pre-treated box.  The earth faces of the underpin recess shown here have been cut with air spades through the treated ground to form the required shape into which the lower underpin (wall and base of the swimming pool) will be cast.  Despite the stabilised sand and gravel being dry and self-supporting the back of the underpin is shored for safety, as required by construction legislation.