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An Unusual Case of Underpinning and Strutting for a Deep Excavation Adjacent to Existing Buildings

Un cas inhabituel de reprise en sous-œuvre et d'étaiement pour une fouille profonde exécutée au contact de bâtiments existants

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Summary

Some new flats, at present under construction in London, are being provided with underground basement car parks. This necessitated excavating 35 feet below existing road levels, passing through sands and waterlogged gravels into the London Clay underneath. In order to do this without endangering the surrounding roads and adjoining brick buildings some 200 years old, it was decided to inject chemicals into the sands and gravels to stabilise them, to excavate and construct the reinforced concrete foundation rafts over the centre of the site from which to support the stabilised soils at the sides, followed by excavating up to the perimeter of the site and completing the construction of the rafts, and then the basement retaining walls and floors.

The results achieved have enabled the usual underpinning of adjacent buildings to be omitted.

The paper explains the various problems, including the nature and strengths of the soils encountered, and gives detailed descriptions of the design and methods adopted, comparing them with more conventional solutions.

Sommaire

On construit en ce moment à Londres de nouveaux immeubles avec garages en sous-sol. Le rapport décrit un cas où on a du faire la fouille à travers du sable et gravier gorgé d'eau et dans l'argile. La profondeur d'excavation au-dessous du niveau du sol était de dix mètres. On a tout d'abord stabilisé le sable et gravier par injections chimiques pour pouvoir exécuter l'excavation parce qu'il y avait autour du chantier des rues et des bâtiments anciens datant environ de deux cents années. On a ensuite construit le radier de béton armé au centre du chantier; ceci a permis de maintenir le sol stabilisé sur les côtés. Ensuite on a excavé jusqu'aux limites du chantier et complété le radier, les murs et les planchers du sous-sol. On a pu, grâce à cette méthode, éviter d'étayer des bâtiments autour du chantier.

Les auteurs ont décrit les différents problèmes qui ont du être résolus, la nature et la résistance des sols qu'ils ont trouvés, le détail de leurs calculs et ils ont fait une comparaison avec les méthodes d'excavation normales.

Introduction

At Great Cumberland Place in the West End of London, a 14 storey apartment building is in course of erection alongside existing late 18th century terrace houses 6 storeys high. The new building is to have underground garages in the basements, and this necessitates excavating 30 feet deep beside the existing brick houses. In London, such foundation work has to fulfil strict by-law requirements and be carried out to the satisfaction of the adjoining owners, the ground landlords, and also the District Surveyor, who has almost dictatorial powers usually wielded in conjunction with a wealth of very practical experience.

The problem was to underpin the neighbouring buildings and support the adjacent roadways in the cheapest a ıd most expeditious manner consistent with safety.

The new building, in reinforced concrete, will consist of a double block of luxury flats, with a tall block of 13 stories and plant floor and a low block of 7 stories, above ground floor level, below which there will be provision for car parking on five levels connected by ramps and including boiler house, tenants' stores, etc. The site is about 160 feet square and the deepest excavation will be 35 feet below road level, extending 7 feet into London Clay. The building is shown in Figs. 1 and 2.

Soil conditions

Three boreholes were made on the site and soil samples were taken and tested.

The boreholes did not differ greatly one from the other, and a typical section is shown in Fig. 3. Road level was at about 90 O.D. and the basement level in the houses was about 80. Down to level 76 the soil was made ground consisting of rubble, ashes, concrete and clay. Below this down to level 62 were the sands and gravels of the Taplow Terrace of the River Thames, with the ground water level at 69. The London Clay was below this, the top two feet being brown and the rest grey.

The top 4 to 6 feet of the Taplow Terrace material consisted of brown and grey medium to fine sands with occasional layers of clay at lower levels. Below this was a mixture of gravels and sands. In borehole 1, there was a layer of brown soft laminated silty clay and sand 4 feet thick below the gravel, but this did not occur in the other holes. The 'N' values for the gravel ranged from 37 to 58. Grading curves given in Fig. 4 indicate the range of the granular soils encountered.

The London Clay was typical of this formation being fissured and stiff, and undrained compression tests on the top 10 feet gave a shear strength of the order of 1 700 lb. sq. ft.

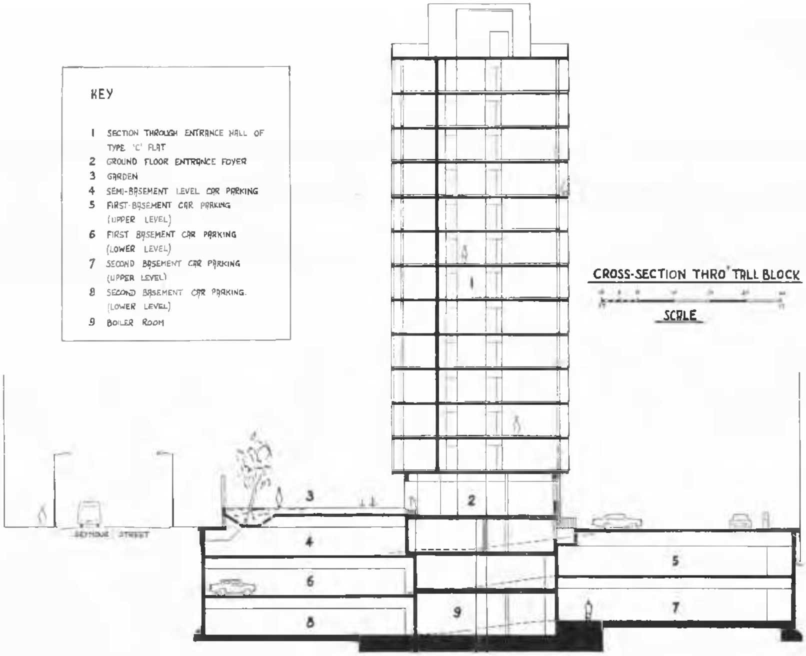

Fig. 1 Cross section through tall block.
Coupe suivant le grand bâtiment.

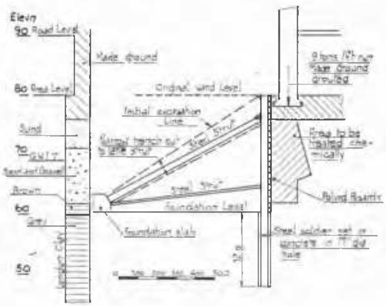

Fig. 3 Soil section and underpinning.
Coupe du sol et échelle de la reprise en sous-œuvre.

Fig. 2

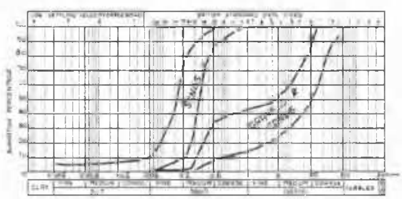

Fig. 4 Particle size distribution.
Analyse granulométrique.

Conventional Solution

The usual method of underpinning the neighbouring buildings would be to go down in timbered pits at intervals under the walls to the level of the new foundation alongside, to fill these pits with brick or concrete, and pick up the buildings on the piers so formed. Intermediate pits would then have to be sunk to form a continuous wall through the sand and gravel layer, although it is possible that this would not have been required by the District Surveyor in the London Clay. This would have been extremely difficult to do through the gravel below water level without losing material into the excavation.

A reinforced concrete gravity angle retaining wall would probably have been constructed all round the site in short lengths in pits in underpinning sequence, followed by the removal of the dumpling. All this would necessitate a large proportion of the excavation being carried out in heavily timbered pits by hand.

Sheet piling would considerably help the work but its use in this case was rejected because of the risk of damaging the rather delicate neighbouring buildings.

Suggested Alternative

The alternative proposed was to inject chemicals into the sands and gravels to solidify them and to support horizontally the wall so formed by vertical steel soldiers placed in holes drilled through the gravel and into the clay, and supported at the top by raking steel struts whose toes would bear on the edges of the concrete foundation slab placed in the centre of the excavation. This would be possible because as soon as the chemical work had been completed it would be safe to dig out the centre of the site leaving a sloping berm to support these treated gravel and sand walls. Thus nearly all the excavation could be done by machine and the slow underpinning by hand in pits would be avoided (Fig. 5).

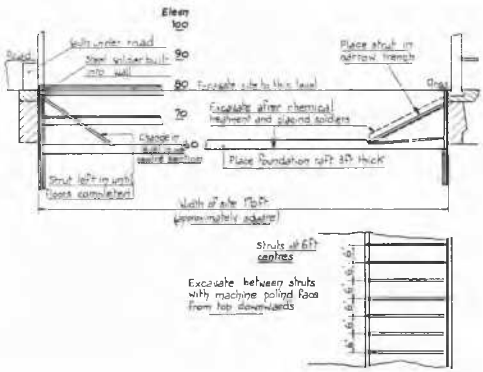

Fig. 5 Typical cross section.
Coupe type.

Whichever method was used, it would be necessary to support the neighbouring buildings above ground by raking shores either of timber or steel scaffolding.

Sequence of Operations

The following sequence of operations was proposed and was carried out with only minor modifications :

1. Erect temporary shoring against walls of buildings, founded on pads below the level of the new foundations.
2. Grout the made ground below and around the footings of existing buildings using cement grout (it was found that in places the old footings were actually on the fill). The purpose of this was to fill any voids in the fill material and prevent leakage of chemical grout at a later stage.
3. Inject chemical grout into the sands and gravels to solidify the block shown in Fig. 3.
4. Bore vertical holes 17″ diameter through the sands and gravels and 12 feet into the clay. Insert steel soldiers in the holes, setting them in concrete in the clay and backfilling above with sand around the soldier as the boring tube is withdrawn.
5. Excavate in the centre portion of the site as shown on Fig. 5, and cast foundation slab in this area.
6. Opposite each steel soldier excavate a narrow trench and erect a steel raking strut with the foot bearing on the concrete slab.
7. Continue excavation between the struts downwards, supporting the excavated face by specially fabricated steel poling boards next to buildings and hit and miss timbering in other areas, place horizontally and supported by the soldiers.
8. When this excavation is halfway down the face, excavate a further narrow trench at each strut and place a further strut as shown on the drawing. The purpose of the second struts is to reduce the bending moments in the soldiers.
9. Continue the main excavation down to foundation level supporting the face as before.
10. Extend the raft slab up to the edges of the site. Construct walls and floors. Box around the steel struts and leave them in. Soldiers are concreted into the walls, and concrete is poured directly up against the steel poling boards alongside buildings, but the timbering at roads etc. is removed as the new retaining walls are cast.
11. When floors are complete across the site, cut out the steel struts and make good floors.

Advantages of Method

This method of carrying out the underpinning operations has several advantages over the traditional method. These are :

1. It is safer since there is no danger of loss of ground while digging.
2. Excavation in the centre of the site can start at any time, and be completed up to the side slopes as soon as the chemical treatment is finished.
3. Practically all of the excavation can be done by machine, with a consequent saving of time.
4. Since the raft slab is placed as soon as the site is excavated the construction of the walls is done on a clean working site.
5. The grouting around the perimeter of the site reduces the amount of water which flows into it, and the central excavation acts as a drain. Water and pumping problems are therefore minimised.
6. The retaining walls can be designed as slabs spanning vertically between floors, assisted by the encased soldiers, instead of as gravity cantilever walls. There is a considerable saving in materials here.

Earth Pressure Calculations

Although the treated soils have considerable strength, it was felt to be sound engineering practice to design the soldiers and struts to take the full lateral earth pressure. In the case of the horizontal poling boards higher stresses than normal were used since it would not be too difficult to replace these if necessary. This would not be possible in the case of the soldiers and trusts.

The lateral pressure due to the soil itself was calculated in the usual way using $\varnothing = 35°$ and $\gamma = 120$ lb./cu. ft. for the gravels and sands, and $c = 1\,500$ lb./sq. ft. and $\gamma = 120$ lb./cu. ft. for the clay.

The lateral pressure due to the weight of the existing buildings on the top of the sand (9 tons/ft. run) would be considerable without the chemical treatment and this pressure was designed for. It was assessed in two different ways. The equivalent horizontal load was calculated by the method given in the Code of Practice for Earth Retaining Structures. Secondly the vertical pressure due to the wall load was calculated by Newmark's method at different depths and this was multiplied by K to give the lateral pressure at the same depths. These methods were in fair agreement as shown in Fig. 6.

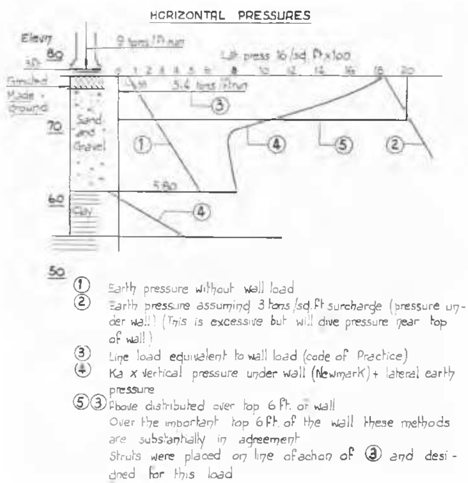

Fig. 6 Horizontal pressures.
Pressions horizontales.

A check was made on the compressive stresses in the treated soil. It was considered safe to assume a minimum unconfined compressive strength of 200 lb./sq. in. (and this strength was specified). This, with a $\varnothing$ of 35° is represented in Fig. 7 by the large circle. The small circle shows the compressive stress due to the wall load. The factor of safety is about 4. Further, a horizontal layer of weakness in the treated material, due for instance to a thin clay layer, is not dangerous since the failure would take place on an inclined plane.

The stability of the toes of the soldiers against kicking out was next checked by an approximate method. The shear strength of the clay was taken as 1 500 lb./sq. ft. at level 56 increasing to 3 000 lb./sq. ft. at level 46. The clay above level 56 was not taken into account. The toe was treated as a vertical footing 17 wide" (the width of the concrete in the bored hole) with a resistance of $2c$ at level 56 increasing to $9c$ at level 46. A spacing of 10 feet for the soldiers, which was the maximum considered for practical reasons, gave a factory of safety greater than 4.

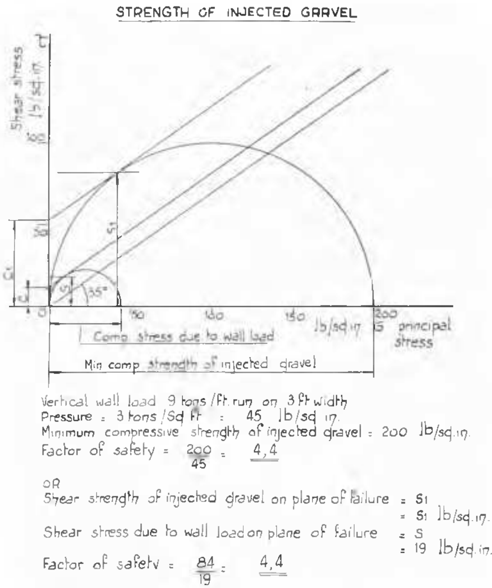

Fig. 7 Strength of injected gravel.
Résistance du gravier injecté.

In the design of the soldiers it was found useful to place the top strut opposite to the line of action of the horizontal load from the wall load. This reduced considerably the bending moments in the soldiers.

The actual spacing and sizes of the struts and soldiers and poling boards were finally decided on practical considerations and were :

1. spacing of soldiers and struts, 6 feet opposite buildings and 8 feet at roads;
2. size of soldiers, 10" × 6" joists at buildings and 12" × 6" joists at roads;
3. sizes of struts, 10" × 10" joists and 8" × 8" joists;
4. types of poling boards, steel at buildings and timber elsewhere.

The pressure on the top of the London Clay due to the load of the existing building was checked for the condition when the clay to one side of the wall had been excavated. The strength of the clay, measured in undrained tests was 1 740-lb./sq. ft. Thus the vertical pressure which would just overstress the clay is 2·5 tons/sq. ft. The vertical pressure at the top of the clay due to the wall load on the gravel is 820 lb./sq. ft. To this is to be added the pressure due to the weight of the soil itself, viz : 1 920 lb./sq. ft. making a total of 2 740 lb./sq. ft. = 1·2 ton/sq. ft. The clay will therefore, not be overstressed.

Execution

The contractors for the specialist work (The Cementation Co. Ltd.) chose to use their T.D.M. process for the chemical grouting. This is a single solution process using a lignosulphonate base, in which the gelling time can be controlled by varying the proportions of the chemicals used.

Following a trial on the site, the procedure originally suggested was modified somewhat. The arrangement of injection pipes used is shown in Fig. 8. First a clay-cement

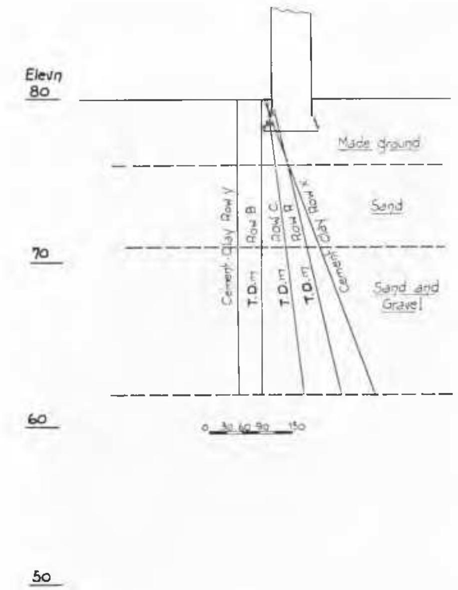

Fig. 8 Arrangement of injection pipes.
Disposition des tuyauteries d'injection.

mixture was injected through pipes *X* and *Y* right down to the clay. The purpose of this was to fill any voids existing in the made ground, to treat any areas in the gravel where the voids were larger than usual, and to confine the very much less viscous T.D.M. to the material beneath the footing. The T.D.M. grout was then injected into the sands and gravels in rows *A*, *B* and *C* and where difficulties were experienced due to ground leakages, the holes were re-drilled and again injected, with particular reference to the finer sands above the gravel layers.

The holes in rows *X* and *Y* were at 4 ft. centres and those in the other rows were at 2 ft. centres.

It is of interest to note that the length of ground treated was 694 feet with an average depth of 12 feet, and that an average of 1·3 gals. of T.D.M. solution was accepted by each cubic foot of soil after the coarser voids had been filled by the clay-cement grout. The injection pressure for the clay-cement was $3 \times D$ lb./sq. inch where $D =$ the depth of injection in feet, with a maximum of 50 lb./sq. inch, but the quantity of material injected was limited to a maximum of 20 gals. per ft. stage. For the chemical injection, the pressure was limited to a maximum of $1\frac{1}{2} \times D$ lb./sq. inch and the quantity to 9 gals. per ft. stage. The chemical grout was mixed to give a gelling time of one hour and discarded one half hour after mixing.

The injection tubes were normally driven into the soil by pneumatic hammers working in a guide frame to obtain the correct angle of rake. When treated soil proved too hard for this, holes were pre-drilled for the tubes. The clay-cement grout was injected through open ended tubes, provided with expendable driving points, and the chemical grout through pointed tubes perforated over a length of 12″.

Another modification was that the soldiers were placed before the chemical work was carried out. This work was also done by the specialist contractor.

The excavation and placing of the struts were done by the main contractor Messrs. Percy Bilton, Ltd.

Result

At the time of writing, the soldiers have been installed and the injection work has been completed. Excavation is well under way and is down into the clay in places. Very little water is flowing into the site showing that the treatment has been generally successful in the mixed gravels and sands. Four trial pits have been dug alongside adjacent buildings in order to see if the results are good enough to dispense with traditional underpinning. Owing to variations in the soils encoutered these show some lack of consistency in the "take" in the finer and more compact sands overlaying the gravel, and the results vary between a soft sandstone and pockets of untreated material. Nevertheless, the latter appear to occur only in small areas and the result generally is considered to be adequate for its purpose. One trial hole was taken down to the clay and showed the treated gravel to be very hard.

It has been decided to further vary the excavation procedure opposite adjoining buildings as follows : Excavate 3′ in depth between a pair of soldiers, i.e. over a width of 6′, and cast an *in situ* reinforced concrete wall against the soil, spanning between the soldiers. This is to be repeated in a proper sequence until the top strip of excavation and walling, 3′ deep has been completed for the full length of the adjoining building. The next 3′ of excavation below is then to be carried out in the same way and the process continued downwards until the R.C. wall overlaps with uniformly treated materials, which will probably be the mixed gravels and sands. Pockets of untreated sand will be replaced with concrete as the excavation proceeds.

Two photographs Figs. 9 and 10, have been included to give an idea of conditions soon after injection commenced. Photograph Fig. 9 was taken to show an injection plant in

Fig. 9

a corner of the site with a guide frame for lowering the injection tubes near to the right hand edge. Shores to an adjacent building 80′ high with injection plant by the left hand shore appear in photograph Fig. 10.

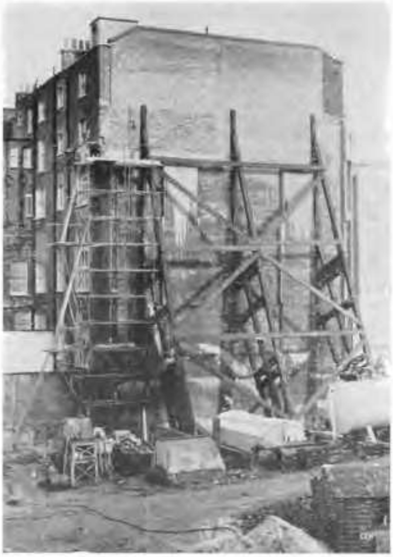

Fig. 10

Two further photographs exhibit present conditions (June 1960) at two corners of the site. Photograph Fig. 11 shows some rakers in position, and the excavation down to formation level, with hit and miss timbering between soldiers. The site is very congested, and it was decided to place the concrete mixing plant in this corner ahead of the general programme. As the foundation slab had not been cast, it was necessary to support the lower ends of the rakers on a concrete toe cast in the clay below the level of the new foundations, which will be cast in this area as soon as possible to accommodate the mixing plant.

Fig. 11

Photograph Fig. 12 was later taken from a viewpoint similar to that used for photograph Fig. 10, the excavation having been taken down to side slopes pending casting the main foundation slab and fixing the rakers. The general excavation was removed using a ramp of horse-shoe shape in plan, and the ramp itself is being removed by means of a dragline excavator.

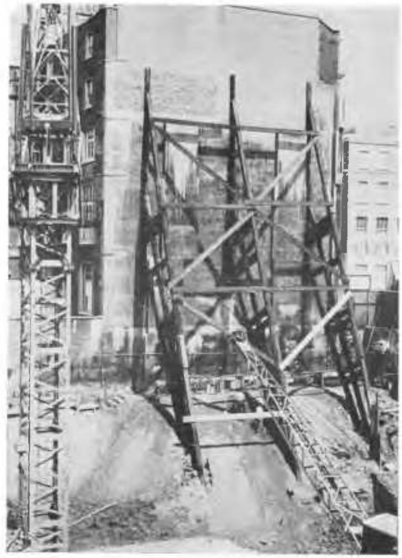

Fig. 12

So far, the work has proceeded smoothly and there is no doubt that the method used has greatly facilitated the foundation work and proved better in every way than the traditional approach.

Acknowledgements

Messrs. Percy Bilton, Ltd. are the owners of the site and are carrying out the foundation and building work themselves. The authors are indebted to the Directors of Messrs. Percy Bilton and especially to Mr. R. J. Woolacott, the Director in charge of this project, for their permission to publish this account of the work. Messrs. Jenkins and Potter are the Consulting Engineers for the project and Dr. Golder was the specialist consultant on the foundation problem. On his departure to Canada, soon after the start of the work, Mr. H. J. B. Harding acted as specialist consultant in his place.

The authors also wish to acknowledge the valuable assistance of Mr. Neal of Messrs. Jenkins and Potter, and the constructive resistance of Mr. Fisher, District Surveyor for St. Marylebone, who tempered his authority with wisdon in departing from tradition.