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TN478 GROUND ENGINEERING GROUP

Ground anchorages: drillhole alignment determination at the British Library, Euston

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Introduction

Construction of the New British Library, Euston, has been under way since 1982, the project being managed for the British Library by the Property Services Agency. Ove Arup and Partners are the project structural engineers responsible for all geotechnical and structural design. Foundation works have included the installation of secant piles, forming the perimeter retaining walls, and large diameter bored piles in the deep basement areas, and have been described in *Ground Engineering*.[1] For the shallower basement areas located above the London Underground Victoria Line tunnels the construction of raft foundations in open excavation has necessitated the use of approximately 260 underreamed clay anchors. These have been used to provide restraint to the secant pile walls and to temporary sheet pile walls forming the northern boundary to the current phase of work.

2. This Technical Note outlines the arrangement and location of ground anchorages developed to provide the required restraint to the wall and describes the methods used to form the anchorage. It also describes experience gained in controlling and determining drill hole accuracy using the Fotobor. A description of the proprietary anchorage system, method of fabrication of the anchor tendon, and the major design parameters are given by Raison.[2] A description of the Fotobor device and its method of use are given by Harris.[3]

Location and arrangement of ground anchorages

3. Ground anchorages were required to provide restraint to the perimeter retaining walls during construction of the shallower basements for the British Library (Fig. 1). The underlying London Underground Victoria Line tunnels precluded the use of piles which were installed for the deeper basement. A raft foundation solution was therefore adopted to be constructed in an open excavation.

4. Ove Arup and Partners were responsible for the overall analysis and design of the retaining walls and, in the manner described by Mitchell,[4] were also responsible for certain aspects of the anchorage system. Results of finite element computations were used to obtain the required levels of propping and the required anchor prestress. The primary function of the ground anchors was to minimize movement in the soil mass outside of the site. To reduce the effects of the anchor loads on the tunnels and structures located close to the anchors, zones were defined in which the anchorage fixed lengths were to be located (Figs 2 and 3). As a result of the design requirements long anchors, up to 40 m in length, were required at horizontal spacings of about 2 m, and a vertical spacing between 2·5 and 3 m.

Written discussion closes 14 August 1987; for further details see p. ii.
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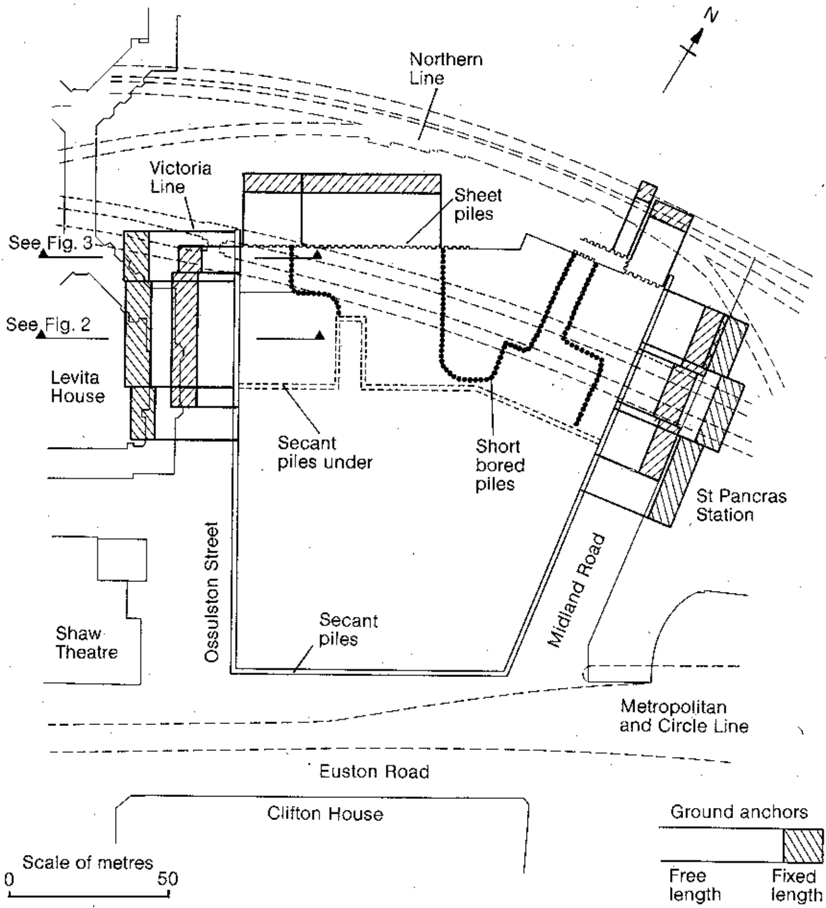

Fig. 1. Site layout

However, because of the drilling methods it was expected that long anchors could deviate significantly from their intended alignment and it was decided at an early stage that the achieved drilling accuracy be determined.

5. Figures 2 and 3 also illustrate the construction sequence adopted in the shallow basement areas. Anchors were installed from a 10 m wide trench adjacent to the retaining walls at progressively lower levels as shown in Fig. 4. Excavation was permitted to proceed only after stressing of all anchors at each level. This procedure enabled the support to the walls to be provided before major excavations within the centre of the site commenced.

Description

6. The contract for construction of the anchorages was awarded to Fondedile Foundations Limited who were responsible for all drilling and installation works.

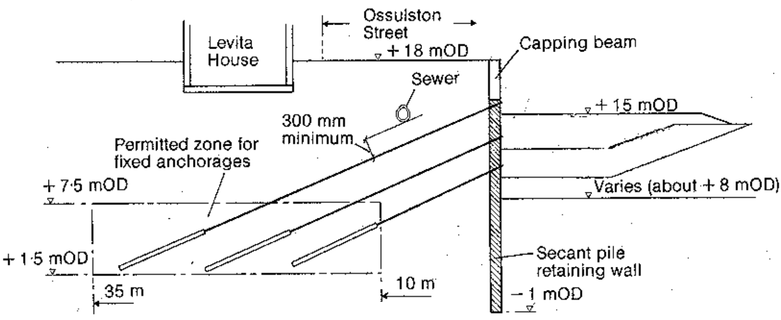

Fig. 2. Section showing ground anchors

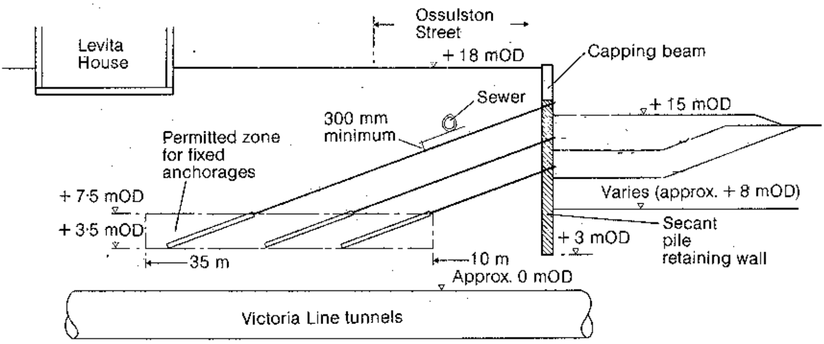

Fig. 3. Section showing ground anchors above Victoria Line tunnels

Fabrication of anchor tendons and stressing operations were subcontracted to Losinger Systems Limited, now VSL Systems Limited.

7. The proprietary anchorage system proposed comprised an augered drillhole nominally 170 mm diameter with underreams or 'bells' about 540 mm diameter at 1·1 m centres forming the fixed length.

Construction

8. Construction of the three trial anchors and all contract anchors was carried out in a similar manner. Installation was carried out from a level working platform formed from rolled hardcore, between 0·5 and 1 m below the anchor entry level. A shallow trench was excavated adjacent to the secant pile retaining wall to facilitate removal of drilling water and spoil to settling ponds located centrally between the east and west walls. All drilling was carried out using self powered tracked boring machines with adjustable drilling heads to cater for inclined anchors.

9. For all anchors a cased access hole was drilled through the retaining wall using a 203 mm outside diameter tungsten carbide crown core barrel. Anchors were drilled through the junction between individual 1·2 m diameter piles at about 2 m centres which eliminated the need for a waling beam. Temporary anchors for the sheet pile walls along the northern boundary of the site (Fig. 1) required a steel waling beam with anchors drilled through the pans at 1·7 or 2·5 m centres. Temporary liner casing remained in place throughout the period of construction.

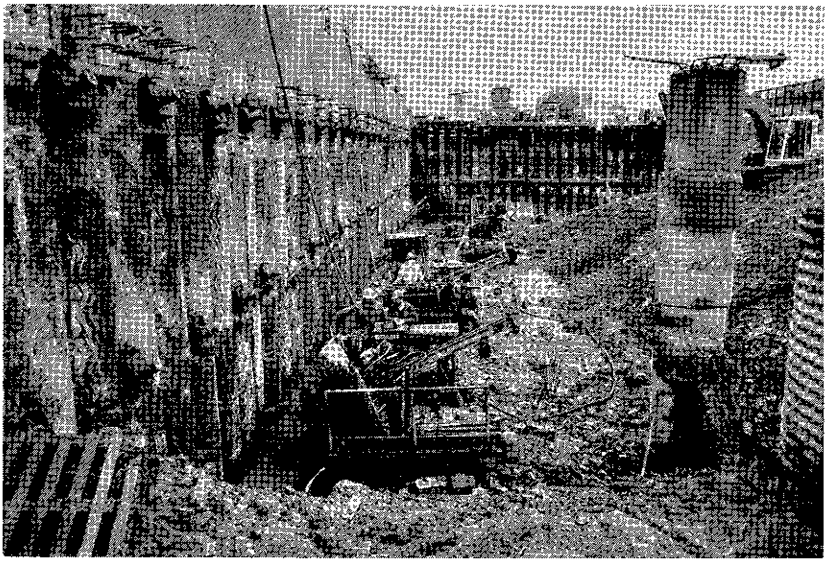

Fig. 4. Installation of ground anchorages

10. Following completion of the access hole the anchorage shaft was formed using a continuous flight stem auger. Each section of auger was approximately 1·5 m long and 160 mm in diameter pinned at each joint. The auger string was fitted with a 170 mm diameter cutting shoe and was top driven by the drilling machine. All augering was carried out dry without any flushing.

11. The fixed length of each anchorage comprised between three and eight 540 mm diameter underreams or bells at 1·1 m centres. Underreaming was carried out with a proprietary tool that forms all underreams simultaneously. The tool gradually opens under load applied by the drill head and rods while the base of the tool bears against the base of the drillhole. During underreaming, spoil was removed from the hole in the form of a slurry by pumping water by way of drill rods into the hole. The slurry was channelled into the slurry trench and pumped to settling tanks.

12. Completion of each anchorage was carried out immediately after underreaming to minimize softening of the surface of each underream. Each anchorage was flushed with clean water and then grouted using a 50 mm diameter tremie tube inserted to the base of the drillhole. After completion of grouting the tremie tube was removed and the prefabricated pre-encapsulated anchor tendon was inserted into the drillhole. On the final homing the protruding length of tendon was measured and the anchor checked to ensure it had been pushed to the base of the hole. Grout was then washed out from the hole for about 3 to 4 m to ensure a separation between shaft and wall.

Deviation of anchorages

13. Pre-contract discussions with specialist ground anchor contractors suggested that deviations of anchor alignment of up to 1 in 30 were possible but 1 in

80 was more often realized. However, on further investigation it became clear that the specialist contractors had carried out almost no measurement of achieved drilling accuracy.

14. The proximity of the Victoria Line tunnels and the need to install anchors to within 3·5 m of the tunnel crown in order to maximize anchorage capacity necessitated drilling accuracy better than 1 in 30. Because of the need to reassure London Underground that anchors would not damage the tunnels, either by the auger or the underreaming tool striking the lining or by load transfer, it was essential that the achieved accuracy be established. This would have the secondary effect that the likelihood of adjacent anchors interacting due to misalignment could also be determined. It was therefore decided that dip and direction measurements would be done for all trial and about 10% of all contract anchorages.

Measurement of dip and direction

15. Determinations of anchor alignment were carried out using a Craelius ABEM Reflex-Fotobor dip and direction indicator by Foraky Limited, now the British Drilling and Freezing Company Limited. A full description of the Fotobor device, the method of use and processing of results is given by Harris.[3] Measurements were recorded photographically to give deviation from an initial dip and direction at intervals along the anchor drillhole immediately after completion of the anchorage shaft before underreaming. To enable measurements to be taken in the 170 mm diameter shaft, 80 mm internal diameter tubing in 6 m lengths were first inserted using centralizers to maintain position. Measurements were taken at 1·5 m intervals and were subsequently processed using an initial dip and direction measured on the body of the Fotobor in its start position. Results were processed generally within one or two days after logging and were presented in tabular and graphical form.

16. During the anchoring works a total of 31 dip and direction determinations were carried out, including the three anchors installed during the anchor trials. The results have been summarized and are shown in Table 1. Results are presented as the difference between the actual location and the intended location in both the vertical and horizontal directions. The table also includes the intended anchor dip angle, the measured dip angle and overall length for each anchorage.

Drilling accuracy

17. The design requirements and the restrictions imposed by the structure and the ground necessitated long anchors, up to 40 m in length, at close spacing. It was expected that because of the nature of the drilling procedures that the anchors would deviate from their intended alignment. The amount of deviation would depend on the accuracy of setting up the drilling rig, the flexibility of the auger string, and the presence of obstructions such as claystones.

18. It was considered that the accuracy of setting out could be controlled by careful supervision and checking. However, use of a continuous flight auger formed from short sections pinned at the joints would result in an inherently flexible system. Control over dip or direction was not thought possible once augering had started and the nature of the boring equipment would result in a tendency for the hole to spiral. It was also thought obstructions in the path of the auger string such as fill material, old footings or claystones could lead to significant deviation in anchor alignment. Unless recourse is made to a core barrel, alignment could only be corrected by grouting and redrilling.

Table 1. Results of the drillhole dip and direction determinations

Anchorage	Required dip: °	Actual initial dip: °	Actual length: m	Surveyed length: m	Distance of base of anchorage from intended location	
					Vertical: m	Horizontal: m
T1	20·0	19·2	35·5	34·5	1·78	2·65
T2	22·9	23·7	35·9	34·5	0·11	1·37
T3	23·4	23·7	31·8	31·5	−0·48	0·53
5A	20·0	20·2	36·6	31·5	−0·22	−0·85
6A	20·0	19·2	36·6	33·0	0·71	0·66
15A	22·9	22·3	46·0	40·5	1·39	0·56
3B	20·0	22·5	27·8	24·0	−1·37	0·04
15B	23·4	24·8	29·0	24·0	−0·01	0·33
25B	24·4	24·5	27·8	24·0	0·11	0·21
3C	20·0	20·2	20·5	18·0	0·09	0·24
5C	20·0	21·0	20·5	18·0	0·32	0·61
15C	24·4	25·6	21·8	18·0	0·36	0·06
20C	24·4	25·4	21·8	18·0	−0·03	0·03
4D	23·4	23·4	29·0	30·0	0·88	0·85
9D	23·4	23·4	29·0	20·0	0·21	1·00
16D	20·0	19·6	36·5	33·0	−1·33	−0·19
17D	20·0	19·6	36·5	33·0	−0·99	0·20
20D	20·0	20·0	36·5	33·0	−0·09	0·14
28D	23·4	23·5	31·5	33·0	0·94	0·26
15E	20·0	21·5	27·8	25·5	−1·51	−0·22
16E	20·0	21·0	27·8	24·0	−0·33	0·28
24E	23·4	24·7	29·0	25·5	−0·38	0·06
15F	20·0	21·8	20·5	18·0	−0·40	0·03
20F	20·0	19·0	20·5	18·0	0·53	−0·15
B104	21·0	21·7	22·0	18·0	−0·38	−0·10
F104	20·0	19·7	24·0	21·0	0·05	0·04
G106	20·0	22·8	20·0	18·0	−0·65	0·06
G112	20·0	21·8	20·0	14·0	−0·18	0·19
H105	20·0	23·2	20·0	16·5	−1·13	−0·01
H112	20·0	21·0	23·5	18·0	−0·32	−0·12
H121	20·0	21·2	20·0	18·0	−0·43	−0·06
				+ve	up	right
				−ve	down	left

19. The results of the dip and direction determinations confirmed that anchors do deviate from their intended alignment by as much as 3 m. However, for comparative purposes the surveyed length of each anchor must also be considered when determining drilling accuracy. Fig. 5 shows a summary of the results in terms of deviation from an intended alignment.

20. Results for the three trial anchorages show deviations of 1 in 11, 1 in 25 and 1 in 44 for anchors T1, T2 and T3 respectively. The maximum specified deviation from the intended alignment was 1 in 30. Only anchorage T3 conformed to this.

21. For the trial anchors, setting up the rig to drill in the required direction was carried out using a combination of tape and eye, with dip being set and

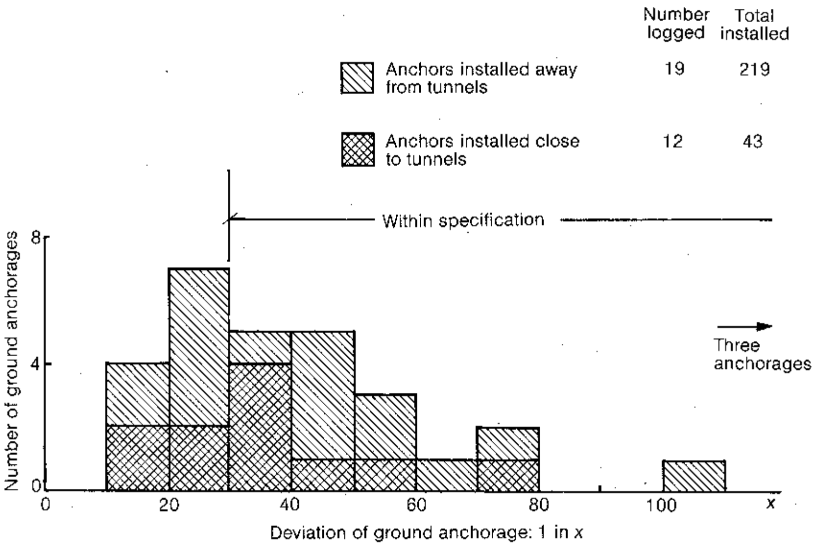

Fig. 5. Distribution of deviation of ground anchorages

measured using a spirit level and steel tape. This method proved complicated and was thought to be inaccurate. Thereafter, in order to improve the accuracy of drilling, all contract anchors were set up using an improved method utilizing a theodolite to set out the direction and a vernier inclinometer (Inogon angle indicator) accurate to 0·2° for setting up dip. Measurements were carried out on the access hole casing and were repeated to ensure accuracy. However, the results shown in Fig. 5 indicate that no real improvement in drilling accuracy resulted with a total of 11 anchors out of 31 showing deviations outside of the specified 1 in 30. Closer examination of the results for these anchors shows that about half resulted from poor set-up with an initial dip up to 3° in error. The remaining anchor deviations resulted from drillhole wander during augering.

22. Figure 5 also shows separately the measured deviations for anchorages located close to the London Underground tunnel and deviations for the remainder of the anchors. No discernible difference in accuracy is evident. However, the proportion of anchors close to tunnels which were logged was far higher, almost 30%. Although the measured deviations were greater than anticipated, the majority achieved accuracies better than 1 in 15 with no anchor deviating sufficiently to the extent that the anchor could damage the tunnels. Based on these results it was possible to reassure London Underground that their tunnels were safe.

Conclusions

23. Dip and direction determinations were carried out for all trial anchors and for 28 contract anchors during installation of about 260 ground anchors at the New British Library. Drillhole deviations were measured using a Craelius ABEM Reflex-Fotobor dip and direction indicator. Approximately 1 anchor in 10 was logged using the Fotobor. About one third of the ground anchors tested show deviations outside the specified 1 in 30. Approximately half of the anchors with

deviations greater than the specified 1 in 30 were the result of poor setting up of the drill rig. The remainder resulted from drillhole wander during augering.

24. Based on the results of the Fotobor logging it was possible to reassure London Underground that their tunnels were in no danger from the ground anchorages.

Acknowledgements

25. The contract for construction of the ground anchorages was awarded to Fondedile Foundations Limited who proposed the fixed anchorage length and were responsible for all drilling and installation works. Fabrication of anchor tendons, stressing operations and component testing was carried out by VSL Systems Limited, and dip and direction determinations were carried out by the British Drilling and Freezing Company Limited.

26. The project is being managed for the British Library by the Property Services Agency, Department of Civil Accommodation. Ove Arup and Partners are the project structural engineers responsible for all geotechnical and structural design. Colin St John Wilson and Partners are project architects and construction management is being carried out by Laing Management Contracting.

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