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TN475 GROUND ENGINEERING GROUP

Ground anchorages: component testing at the British Library, Euston

C. A. RAISON, BEng, MSc, MICE*

Introduction

As part of the anchoring works at the New British Library, Euston, pre-contract anchor trials were carried out to investigate the anchor components and materials, the manufacture and installation of anchors, and to test both the short- and long-term behaviour before proceeding with the main contract. This Technical Note outlines the major design parameters used and describes the proprietary anchor system adopted. The note also describes the component testing carried out as part of the anchor trials to confirm the suitability of materials and methods used to form the prefabricated anchor tendon. Details of the on-site anchor trials, including the installation and testing of three trial anchorages, construction of 260 contract anchors and the results of long-term monitoring of anchor loads will be described elsewhere.

Design of anchorage

2. Ground anchors were required to provide restraint to the secant pile and sheet pile retaining walls forming the perimeter to the shallower basements at the New British Library. Ove Arup and Partners were responsible for the overall analysis and design of the retaining walls and, in the manner described by Mitchell,[1] were also responsible for certain aspects of the anchorage system. Results of finite element computations were used to define the required levels of propping and the required anchor prestress. To minimize the effects of the anchor loads on structures located above the anchors, zones were defined in which the anchorage fixed length was to be positioned.

3. Following preliminary design it was realized that, to provide the required propping with a sensible spacing between anchors, working loads up to 800 kN would be necessary. Anchorages in clay with loads this high were considered unusual and underreamed clay anchors were probably the only effective means of providing the required load capacity. Because of the different proprietary anchorage systems available it was decided that the Contractor should determine the anchorage fixed length, the corrosion protection and monitoring system. This was to be based on design parameters defined in the specification, and to be generally in accordance with the British Standard Draft for Development (DD81).[2]

4. The major design parameters that were defined in the specification are outlined as follows.

(*a*) Design life—this was to be generally up to four years to allow for any construction delays.

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

* Ove Arup & Partners, London.

(*b*) Corrosion protection—because of the uncertain duration of use the major portion of anchorages were regarded as permanent within the terms of DD81. A minimum corrosion protection was required: for the fixed length—corrugated tendon sheathing; for the free length—grease and strand sheathing with additional protection provided by smooth tendon sheathing; and for the anchor head—double protection provided by grease and cover cap.
(*c*) Fabrication—pre-encapsulation of the fixed length was required to ensure a good bond between strand and grout and a high quality fixed length corrosion protection.
(*d*) Fixed anchor—the bond between strand and grout was not to exceed 2 N/mm^2 or the measured bond with a minimum factor of safety of 1·6.
(*e*) Tendon load—the load was not to exceed 80% of the characteristic strength of the tendon at any time, or 50% at working load.
(*f*) Anchorage capacity—the anchorage was to be designed to have a minimum ratio between failure load and working load of 2·5.

Description

5. The contract for construction of the anchorages was awarded to Fondedile Foundations Limited who proposed the fixed anchorage length and were responsible for drilling and installation works. Fabrication of anchor tendons and stressing operations were subcontracted to Losinger Systems Limited, now VSL Systems Limited.

6. The proprietary anchorage system proposed comprises an augered drillhole nominally 170 mm diameter, with underreams or 'bells', about 540 mm diameter at 1·1 m centres, forming the fixed length. This is shown schematically in Fig. 1. A prefabricated pre-encapsulated 90 mm diameter anchor tendon is then grouted into the drillhole using a neat cement grout. The tendon comprised up to six 15·2 mm Dyform strands pre-grouted into corrugated tendon sheathing, the corrugations providing the bond to enable load transfer between the anchor and the underreams. Typical details of the prefabricated anchor tendon are shown on Fig. 2. Within the free length the strand is protected by grease, strand sheathing

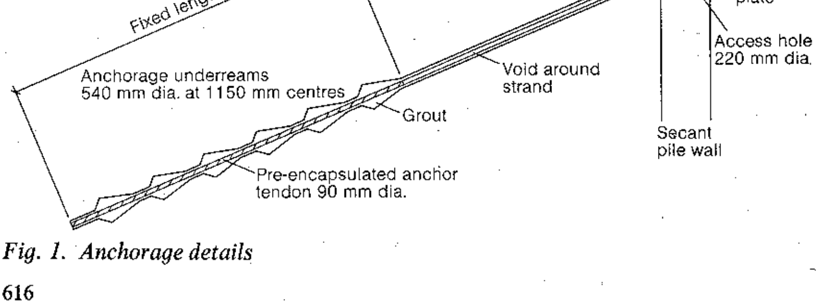

Fig. 1. Anchorage details

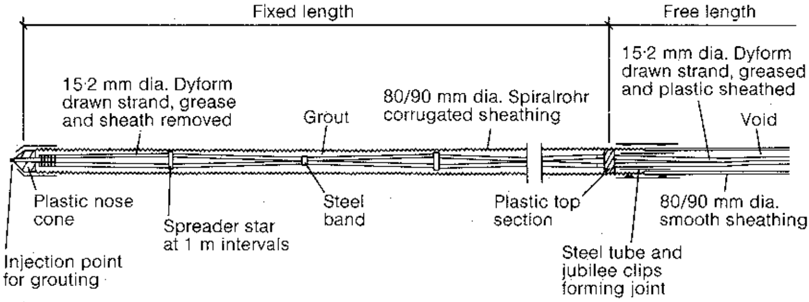

Fig. 2. Pre-encapsulated anchor tendon

and an outer 90 mm diameter tendon sheath for its full length. The annulus between sheathing and the soil is filled with grout. The internal annulus is left as a void.

7. For the secant pile walls, anchor forces were transferred from tendon to wall through a prefabricated steel bearing plate mortared to the secant piles as shown in Fig. 3.

8. For the sheet pile walls a steel waling beam and bearing plates were used to spread anchor forces to the wall.

Fabrication of anchor tendon

9. All test sections, trial anchor tendons and contract anchor tendons were fabricated following the same procedure off site under factory conditions.

10. Greased and plastic coated strand was cut to length and laid on to the fabrication bed. The sheathing was removed from the strand over the length to be pre-encapsulated and the strand degreased using 'Jizer' and then white spirit by unravelling the strand wires and placing in a cleaning bath. The strand was subsequently reassembled.

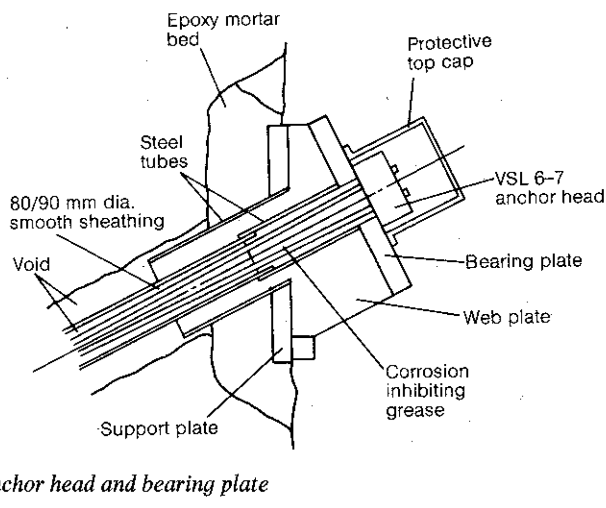

Fig. 3. Anchor head and bearing plate

11. The required number of strands were assembled into a tendon using strand spacers or stars at about 1 m spacing and banding the strand together at the midpoints using stainless steel strap. Spiral corrugated tendon sheathing (Spiralrohr HDPE 80–90 mm diameter) was pulled over the assembled tendon and screwed on to a threaded plastic top section and a plastic nose cone banded to the strand, (see Fig. 2). The lower joint was sealed using a heat shrink band seal.

12. Grouting was carried out by way of an injection hole through the nose cone by pumping upwards through a grout pipe into the anchor. During this operation the anchors were supported on an inclined beam (approximately 1 on 3). Grout was vented from the top of each anchor through a pipe. Samples of the grout used were taken both from the grout pan and the vent and wet densities checked using a mud balance. Grout cubes were also prepared and tested at seven days and at 28 days.

13. After the grout had cured for about 48 hours the inclined beam was lowered to the horizontal. Smooth tendon sheathing (HDPE 80–90 mm diameter) in 12 m lengths was then drawn over the strand group and joined to the corrugated sheathing using a steel tube, clips and heat shrink band (Fig. 2). Subsequent lengths of sheathing were jointed in a similar manner. Each anchor tendon was then coiled on to carrying frames for storage and marked with their reference numbers before transportation to site.

Testing requirements

14. Working loads for the ground anchorages are up to 800 kN. Clay anchors with loads this high are unusual and very little published information about anchor behaviour at these loads exists. It was therefore considered extremely important to carry out trials to determine both short-term and long-term behaviour before the start of basement construction. The trials would also confirm that high capacity clay anchors could be constructed and would enable installation problems to be identified well in advance of the main contract.

15. Following the guidelines of DD81, demonstration of the suitability of the materials, components and method of construction of the anchors was required before acceptance of the anchorage scheme. It was envisaged that this would be done by the presentation of manufacturers' certificates and results of previous testing or research. However, during pre-contract discussions it became clear that very little research or testing to investigate the behaviour and performance of materials or components in regular use throughout the industry had in fact been carried out. As a result, a comprehensive range of materials and components tests were requested.

16. It was considered unnecessary to test the non-structural components such as strand spacers, end pieces or banding or taping materials. Manufacturers' certificates for cement and strand were adequate for these materials. However, tests were required to

(*a*) measure the strand to grout bond
(*b*) demonstrate the suitability of the corrugated sheathing to transfer load from the tendon to the underreams
(*c*) measure the ultimate failure load of the tendon.

17. Trial grout mixes were also required together with other tests to demonstrate the durability of the components, and to demonstrate the suitability of the

methods of fabrication. All tests were proposed and carried out by the contractor before final acceptance of the proposals for carrying out the on-site anchor trials.

Materials

18. Grout used for the trial anchors and all component testing was mixed using ordinary Portland cement complying with BS12 supplied by Blue Circle Industries in 50 kg bags. Water was obtained from the mains supply and Colplus WE, an expanding and plasticizing additive was used.

19. Bridon Dyform strand, greased and plastic coated was used for all testing and fabrication of anchors. Dyform drawn strand complies with BS5896. All strand used was 15·2 mm diameter, nominal area 165 mm^2, stiffness in tension 195 kN/mm^2 and ultimate strength 300 kN.

Grout trials

20. Grout trials were carried out before the other component testing to establish a grout mix for the pre-encapsulated fixed length with a water : cement ratio less than 0·45, a bleed less than 0·5%, but with sufficient workability to be usable. Mixing was carried out using a VSL double drum mixer.

21. The grout mix adopted for all test sections and fabrication of the trial anchors was 50 kg cement, 16 l water, plus one bag of Colplus WE additive. This mix had a water : cement ratio of 0·33, maximum bleed less than 0·5% and compressive strengths at 28 days between 45 and 57 N/mm^2. Wet density measured during grouting using a mud balance gave values between 1·97 and 2·01 g/cm^3. Dry densities of grout cubes gave values between 1·89 and 2·03 g/cm^3. This mix was subsequently modified for the contract anchor fabrication by the increase of water content to 18 litres giving a water : cement ratio of 0·38.

22. Similar grout trials were also carried out to establish a grout mix for all site grouting of the anchorages. The grout mix finally adopted was: 50 kg cement, 20·5 l water, plus 0·2 l BV40 additive. This mix had a water : cement ratio of 0·41, bleed of 0·6% and compressive strengths at 28 days between 55 and 70 N/mm^2.

Anchor test sections

23. As part of the test programme two test sections of the pre-encapsulated fixed anchor were fabricated to demonstrate the ability of the grout to form a homogeneous voidless grout penetrating all the interstices within the corrugated sheathing. This was necessary to ensure structural continuity and to provide as good a protection to the strand as possible to minimize the danger of corrosion. For both sections the grouted length was about 3·4 m long, overall length about 5 m, the fabrication method being similar to that described above. Approximately four days after grouting each test section was cut into short lengths for examination.

24. The first test section when examined showed signs of grout bleed and voids. This can be seen in Fig. 4 which shows that the strand was not correctly centred and the anchor distorted in cross-section. Poor quality grout was suspected due to contamination by water lying in the grout pipes. As a result the contractor agreed to carry out fabrication of a second test section. This second test section was fabricated using strand spacers at closer centres. Better control during grouting resulted in an acceptable homogeneous voidless grout throughout the test section.

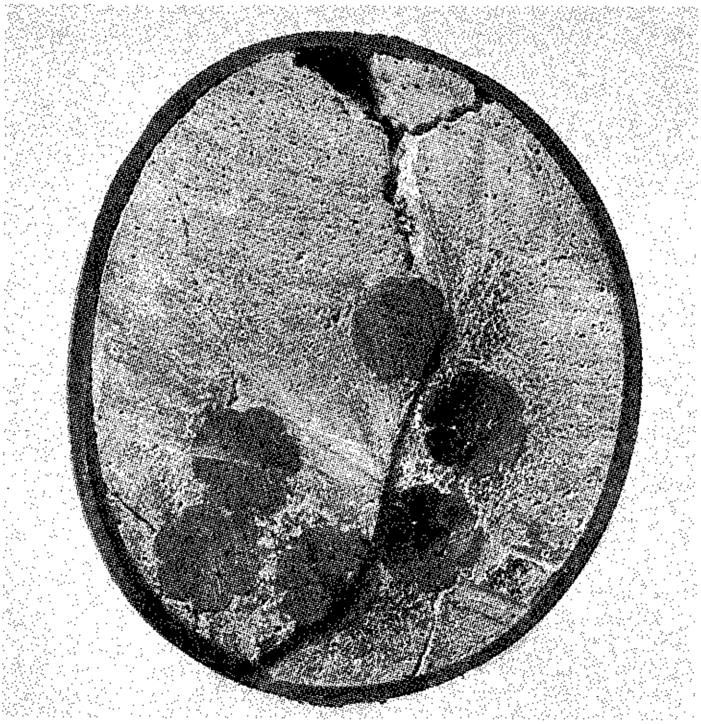

Fig. 4. Anchor tendon test section

Sheathing tests

25. The proposed Dyform strand used for fabrication of the anchors is supplied from the manufacturer greased and plastic sheathed to a nominal thickness between 0·75 and 2 mm. The proposed design intended that the primary corrosion protection would be provided by the strand sheathing. The surrounding tendon sheathing would prevent damage to the strand sheath during handling. Because of this additional protection, testing of the strand sheathing was not considered necessary.

26. The anchor proposals intended that the internal annulus between smooth tendon sheathing and the strand be left as a void, but the external annulus would be filled with neat cement grout. It was considered that during installation there was a possibility that under the grout fluid pressure the tendon could collapse on to the strand causing damage to the sheathing and reducing the corrosion protection. As a result, test lengths of the sheathing were loaded externally to pressures up to 500 kN/m^2, equivalent to a grout head of 25 m. Although the sheathing did deform and collapse on to the strand, no damage to either strand or tendon sheathing was observed.

27. Tests were also required because the corrugated tendon sheathing proposed by the contractor for the anchor fixed length did not meet the specification.

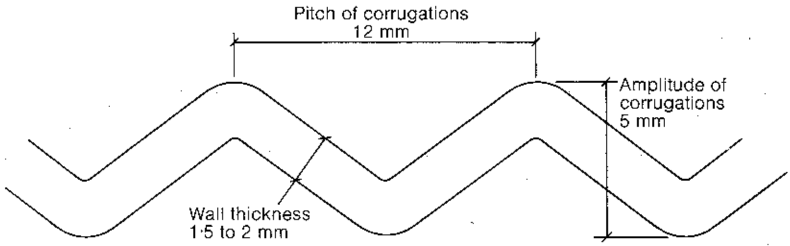

Fig. 5. Corrugated sheathing

In order to ensure adequate mechanical transfer of load between strand and anchorage underreams DD81 recommends that the pitch and the amplitude of the corrugations be at least 12 times, and 4 to 8 times the wall thickness respectively. However, as shown in Fig. 5, both the pitch and amplitude of corrugations were less than these requirements. Because of the importance of demonstrating an effective transfer of load, testing of this mechanical bond was required.

28. The sheathing wall thickness was required to provide sufficient resistance to puncture or other damage during fabrication or handling that could result in

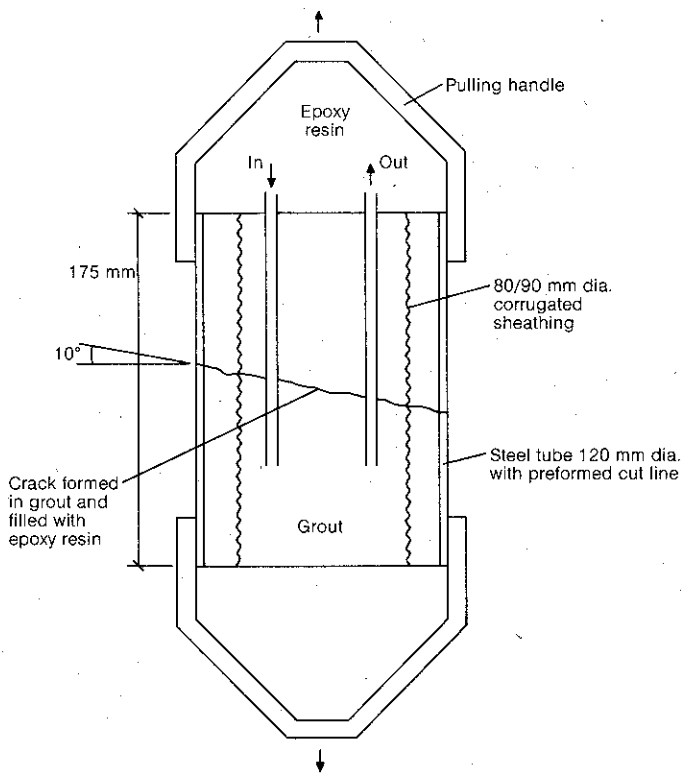

Fig. 6. Tensile test for corrugated sheathing

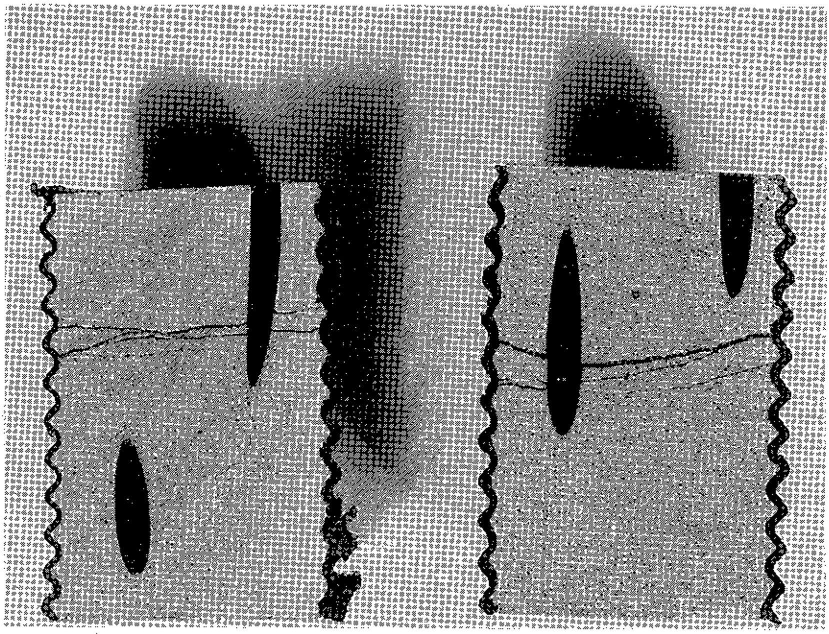

Fig. 7. Tensile test specimens

the corrosion protection being reduced. However, the nominal wall thickness was 1·8 mm compared with a required thickness of 2 mm. Acceptance of the thinner material therefore required care during manufacture and subsequent handling of the anchor. The importance of this was illustrated during the grouting of one of the trial anchor tendons where grout was observed spurting through a split in the corrugated sheathing. This split had been noticed during assembly but sealed with heat shrink band which subsequently failed under grout pressure. The hole was sealed temporarily with mastic and repaired after completion of grouting.

29. This split was one of several observed during the fabrication of the trial anchor tendons. As the sheathing in the fixed anchor is the primary defence against corrosion it is essential not to have any hole or puncture which may allow water to penetrate to the strand. Because of the concern raised the contractor agreed to test all sheathing to be used for the contract anchors. The contractor proposed to 'air pressure test' all sections of sheathing and to reject all damaged or punctured sections. If minor damage or leaking occurred during grouting this would be repaired using heat shrink band. Excessive leakage would result in rejection of the sheathing.

30. The ability of the proposed corrugated tendon sheathing to withstand the effects of localized cracking of the pre-encapsulated grout was also required to be demonstrated. A tensile test was therefore carried out during which two 175 mm long samples of the fixed anchor (without strand) were cracked along pre-determined planes as illustrated in Fig. 6. After injection of epoxy resin to fix the cracks the samples were cut and examined.

31. Both tests demonstrated the ability of the sheathing to remain intact and

watertight with cracks in the grout up to 4 mm in thickness. Fig. 7 shows the results of both tests where cracks were spread over approximately 10 mm, but no damage to the sheathing was detected.

Bond tests

32. Ultimately the load capacity of an anchor depends upon the bond achieved between strand and grout, grout and sheathing, and grout and soil. The latter was proposed to be established during the on-site anchor trials during testing of a prototype anchorage. The bonds between anchor components, however, were to be determined as part of the programme of component testing.

33. The strand–grout bond was measured by casting a single 15·2 mm diameter Dyform strand into a container filled with neat cement grout as shown in Fig. 8. Testing was carried out after seven days when the grout had achieved a

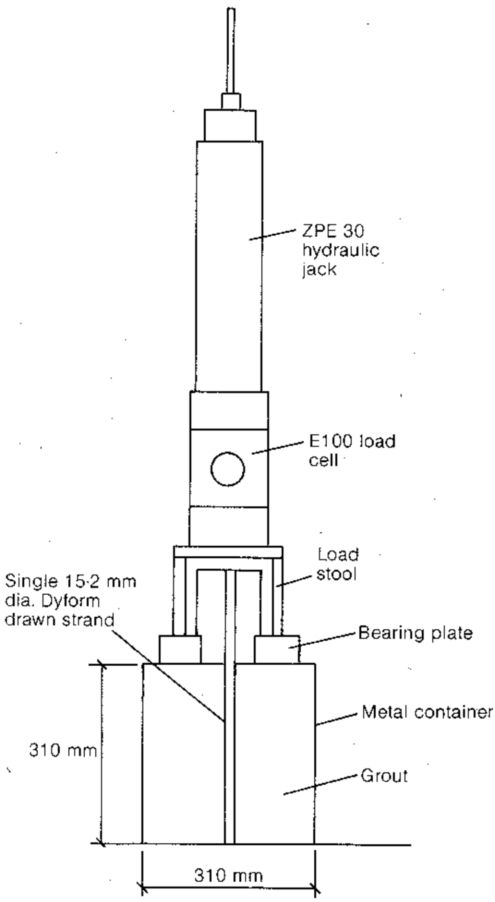

Fig. 8. Strand–grout bond test

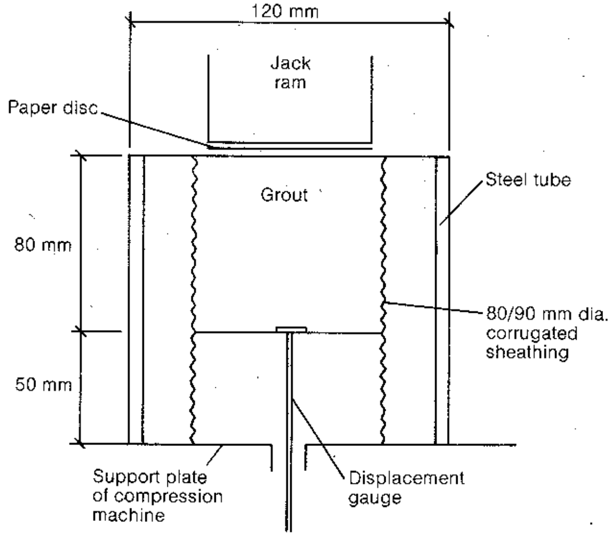

Fig. 9. Push-out test for corrugated sheathing

cube strength of between 37·5 and 44 N/mm^2. A strand–grout bond of 6·2 N/mm^2 was measured, well in excess of the 2 N/mm^2 required by the specification.

34. The grout–corrugated sheathing bond was measured by carrying out three push-out tests. Testing was carried out on 80 mm long test sections of fixed anchor (without strand) as shown in Fig. 9. Testing was carried out when the grout cube strength reached about 35 N/mm^2 using a standard concrete cube testing rig. Peak grout–corrugated sheathing bond strengths between 12 and 13 N/mm^2 were obtained.

35. The ultimate failure load of the anchor tendon was measured by testing two short lengths cut from the test sections after casting them into 200 litre oil drums filled with neat cement grout (Fig. 10). The first test was carried out when the internal grout had achieved a strength of about 40 N/mm^2. However, poor grouting of the first test section resulted in a measured tendon–grout bond of about 2 N/mm^2 at failure, failure occurring by pull out of the strand from inside the corrugated tendon sheathing.

36. Testing of the second test section was carried out when the internal grout had reached a cube strength of about 45 N/mm^2 and the external grout about 70 N/mm^2. At failure the grout–corrugated sheathing bond was about 3·6 N/mm^2 on the inside face. Failure occurred at the strand–grout interface with the strand pulling from the internal grout at a bond stress of about 5·7 N/mm^2 calculated on the nominal perimeter of the strand group. This is comparable to the strand–grout bond measured previously.

37. Although it is realized that different confining stresses act on the anchor tendon in situ it is considered that the results of these tests were relevant in assessing the ability of the sheathing to transfer load. In fact for the contract anchorages the contractor decided to use fixed anchor bond lengths sufficient to restrict tendon–grout stresses to less than 1 N/mm^2.

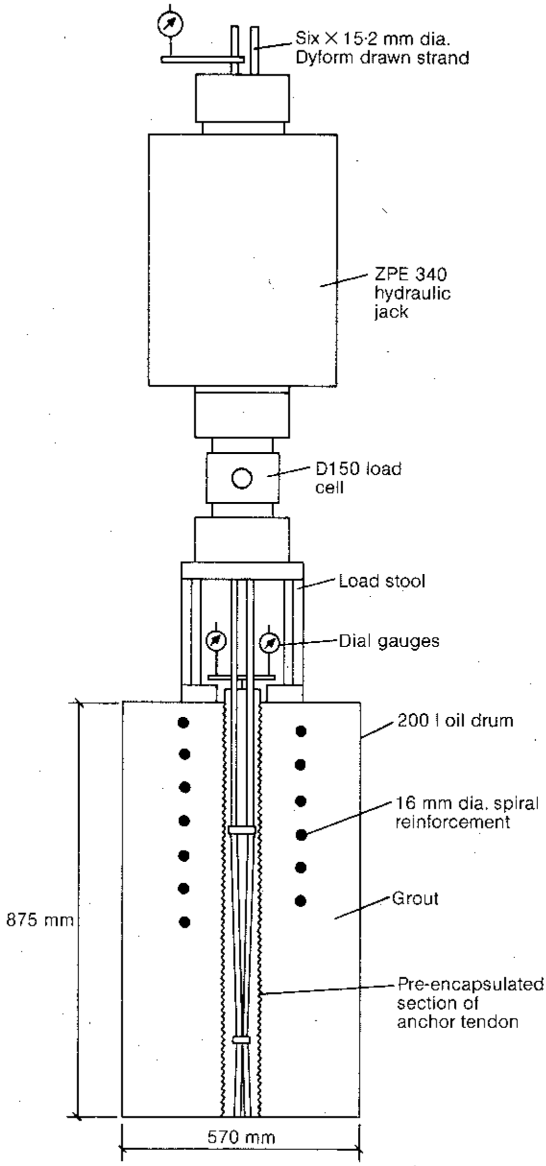

Fig. 10. Ultimate failure load test of anchor tendon

Summary

38. This Technical Note has been written in order to disseminate some of the experience and knowledge gained during the design and pre-contract testing of ground anchorages installed at the New British Library. Following the guidelines of DD81, a programme of materials and component testing was required to demonstrate to the designer their suitability and to investigate methods of construction.

39. The programme of testing was designed to suit underreamed clay anchors. Grout trials were carried out to determine suitable mixes both for the pre-encapsulated fixed length of the tendon, and for the external grout. Component testing was limited to structural items only, with particular regard to durability during handling and during use. Bond tests were also carried out to investigate the strand to grout bond, grout to corrugated sheathing bond and to determine the ultimate capacity of the tendon. Methods of construction were also investigated by the fabrication of anchor sections culminating in the assembly of prototype trial anchors.

40. The results of the testing confirmed the suitability of materials, components and methods of construction.

Acknowledgements

41. 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.

42. 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.

References

1. MITCHELL J. M. Ground anchorages: safety factor selection. *Proc. Instn Civ. Engrs*, Part 1, 1987, **82**, Jun., 607–614.
2. BRITISH STANDARDS INSTITUTION. *Recommendations for ground anchorages*. Draft for development DD81, BSI, London, 1982.