16 Apr 2004, 8:00am - 9:30am

Channel Tunnel Rail Link – Contract 220 Graham Road Deep Vent Shaft

John Coupland
Underpinning & Foundations Skanska, Maspeth, New York

Peter Openshaw
Bachy Soletanche Ltd, Godalming, Surrey, UK

Proceedings: Fifth International Conference on Case Histories in Geotechnical Engineering
New York, NY, April 13-17, 2004

CHANNEL TUNNEL RAIL LINK – CONTRACT 220
GRAHAM ROAD DEEP VENT SHAFT

John Coupland
Underpinning & Foundations Skanska
Maspeth, New York, USA

Peter Openshaw
Bachy Soletanche Ltd
Godalming, Surrey, UK

ABSTRACT

The 53m deep, 1.2m thick, heavily reinforced diaphragm wall, constructed to form this vent shaft, would not normally merit special mention. What makes this project notable is that the work was carried out within the confines of a very small city site, surrounded by residential properties, immediately adjacent to an operating rail line and with strict limits on permitted working hours and noise levels.

This paper describes the construction phase of the work including the planning, preparation, means and methods undertaken to overcome the constraints noted above. Because of the potential problems and consequently the inherent significant construction risk the work was undertaken by a joint venture of two of the largest international foundation specialists even though the monetary value was quite small. At the time both companies considered the work to be at the limits of what was practicably achievable. After successful completion those limits may have been pushed back, but perhaps only a little.

INTRODUCTION

The major civil engineering works for the Channel Tunnel Rail Link (CTRL) Section 2, the 24 miles between Southfleet in north Kent and St Pancras station in central London, began in July 2001.

When complete in 2007, the £5.2 billion ($8.3 billion) CTRL will halve journey times from central London to the Channel Tunnel. The CTRL will also provide for Kent commuters to benefit from new high-speed domestic services to London and back and will create three new international stations at St Pancras, Ebbsfleet and Stratford, in addition to connecting with the existing Ashford International.

Union Railways (North), a subsidiary company of London & Continental Railways (LCR), is responsible for the construction of Section 2.

Rail Link Engineering – a consortium of Arup, Bechtel, Halcrow and Systra - is the designer and project manager of Sections 1 and 2 of the CTRL.

Nishimatsu/Cementation Skanska Joint Venture (NCSJV) was awarded CTRL Tunnels, Stratford to London West portal, Contract 220, for an approximate value £145 million ($232 million), on 16th February 2001. The Works comprise the construction of twin, 7.5km long bored tunnels (internal diameter 7.15m) from Stratford to Kings Cross.

A particularly awkward and potentially difficult part of contract 220 was the construction of a vent shaft on a very small site off Graham road in Hackney East London. This shaft was designed with a 52.7m (173ft) deep perimeter diaphragm wall and an internal excavation depth of 47m (154ft).

A joint venture of Cementation Foundations Skanska and Bachy Soletanche (CFSBSJV) was awarded the subcontract for the diaphragm wall at Graham Road Vent Shaft.

The New Engineering Contract was used for both the main and sub contract. This is a cost reimbursable form of contract aimed at encouraging cooperation and teamwork between the parties by sharing the “gain” or “pain” of cost savings or of cost overruns.

PLANNING AND PREPARATION

Panel Arrangement and Jointing Method

The first decision to be made was how to split up the structure into panel sizes that could be constructed and how to form the joints between the panels.

Standard diaphragm wall excavation equipment cuts a slot 2.8m long (2.5m, 3.2m & 3.5m are also standard but not as common) and this dimension usually dictates the length of the panel. The most efficient arrangement permits excavation of two 2.8m slots with an intervening column of earth, less than 2.8m long, that is excavated last. Thus panel lengths of between about 6.5m and 8m long are generally preferred.

For forming joints between panels the continuous water stop (CWS) system has proved preeminent but until fairly recently was only reluctantly used at depths greater than 35m as removal of the metal section forming the joint, an operation carried out during the later excavation of the adjacent panel, had proved increasingly difficult and time consuming with greater depths.

The introduction of the hydro-mill for excavating diaphragm walls permitted another method of forming joints by cutting into the concrete of previously constructed panels. This system has proved successful for the construction of circular shafts, designed in hoop stress, where the joints are in compression but is not as watertight as CWS where the wall is propped or cantilevered.

The over cutting method does, however, allow small panel lengths. Single cut 2.8m long primary panels can be constructed with spaces of about 2m between them. The hydro-mill then excavates a 2.8m long closing panel by cutting into the concrete of the primary panels on either side.

The initial thinking for Graham Road Vent Shaft (GRVS) was to use this latter method in order to make the logistics involved with bentonite slurry storage, reinforcement cages and concrete easier because the individual panel volumes were minimized. A 2.8m panel length would require nearly 40 metric tons of reinforcement and 180m³ or more of concrete. With the permitted working day starting at 8 a.m. and finishing at 6 p.m., being able to do the final panel cleaning, then lift, splice and place the reinforcement cages, pour the concrete and tidy up on completion all within that 10 hours was originally thought to be challenging enough so the use of longer panels was not considered to be a viable option.

Following the handover of the project to the construction team a review of the intended construction methods was carried out in particular the following aspects:

<u>Over Cut Panel Joints</u>. The ground water level at the site was approximately 35m below ground level during the installation of the diaphragm wall. There was also a perched water table about 4m below ground level. Following diaphragm wall construction the water table was to be temporarily drawn down to below the depth of 47m that the shaft was to be excavated, in preparation for the arrival of the two TBMs. Thus any leakage through the panel joints would not occur until after completion of the main works when the water table rose to its preconstruction level. At that point in time the shaft will likely be fully operational and the consequences of any significant water inflow potentially serious.

The use of the over cut method and short panel lengths would have resulted in approximately 30 panels around the 75m perimeter of the shaft and consequently 30 joints with the potential to leak.

A further constraint of this system is that the vertical deviation, to prevent the hydro-mill hitting the reinforcement steel in the primary panel, would need to be 1:500 or better, possible but difficult to guarantee.

The construction team considered that only the CWS system and a reduced number of joints would provide sufficient confidence to reduce the risk of water leakage to an acceptable level.

<u>Working Hours</u>. The permitted working hours on the site were to be from 8.00 am to 6.00 pm. Extensions up to 10.00 pm were possible if the contractor could show justification and obtained approval from the appropriate local government officials.

The one decision that did not need reviewing was to fabricate the reinforcement cages elsewhere. There was simply not enough space on site. To be able to transport the cages on the public roads, without special arrangements, meant that they needed to be made in sections no larger than 15m by 2.8m. Therefore for a 53m deep panel at least 4 separate sections would require to be offloaded, lifted, spliced together and lowered into place. It was anticipated that at least an hour for each cage section would be required discounting any problems that might arise. Allowing a further hour for the operations of cleaning the bottom of the panel prior to cage installation and installing the tremie pipe afterwards meant the concrete could not start before 1 p.m. leaving a maximum of 5 hours to place 180m³ of concrete.

Outside London such a placement rate would have been quite possible but it was known that local traffic conditions between 4.00 p.m. and 6.00 p.m. were such as to cause at least a 2 hour turn around time for the delivery trucks, more than double the period it would take earlier in the day, even though the nearest concrete plant was less than 10 miles away. Additionally the buoyant London construction market at the time was already stretching the resources of the concrete suppliers and any pour booked to start other than first thing in the morning risked being delayed by over runs at other sites. Realistically a minimum concreting period of 6 hours was to be expected if a start was made in the afternoon.

From the above it can be seen that if the operation ran perfectly the works would still overrun the 6.00 p. m. deadline by at least 1 hour. Allowing for the normal minor delays and problems that occur in even the best-planned operations, completion between 8.00 p.m. and 10.00 p.m. would be the most likely result. As there would be at least 30 such operations to complete the works we would need to seek dispensation for late working at least that number of times.

Large Panels In view of the potential water proofing and late working problems, as described above, the construction team decided to propose the use of larger panels and CWS joints.

Clearly it would not be possible to place the 90t of reinforcement and 400m³ concrete during one 10 hour day so the first step was to seek agreement from the Engineer for installation of the steel cages one day and pour the panel the next day.

Good practice in diaphragm wall construction is to minimize the time between the final cleaning of the bottom of the excavation and the start of pouring concrete. This lessens the build up of solids and gelled bentonite, on the bottom of the panel, around the reinforcement, and at the panel joint, all features that may lead to defects in the final wall construction. To counter such concerns the team undertook to not merely clean the bentonite slurry used for excavating the panel but to completely replace it with slurry that had not been used in the excavation process and therefore had virtually no solids content. They also planned to circulate the slurry in the panel over night, by pumping through the tremie pipes. The next morning, immediately before placing concrete, the panel base would be sounded and bentonite from the bottom of the trench would be sampled and tested.

The other issue requiring the agreement of the Engineer and the designers was the arrangement of the reinforcement. As previously stated the steel cages had to be transported to the site on public roads and as such it would not be possible to use a full width cage .Therefore it was proposed to install 2 cages, each of 4 sections in each panel. Even if full width cages could be provided the small site and proximity of the railway would have prevented the use of a crane large enough to handle the weight. However an unreinforced vertical column in the centre of the panel could lead to concerns over potential cracking in that location.

It was a feature of the contractual arrangement between the parties on the CTRL projects, and the cooperation resulting from it, that issues of this sort were constructively and openly reviewed, discussed and resolved. In this case the Engineer agreed that the construction team's proposal to use larger panels was most likely to produce the best quality product given the constraints on the work.

With agreement to the basic proposals the construction team could start the detailed planning phase. The first thing was to finalize the panel arrangement (fig. 1.) and sizes and locations of the starter (primary) panels and closure (final) panels. The overall size of the shaft dictated a 12 panel arrangement resulting in centre line panel lengths of 6.05m for the corner panels, 6.65m for the starter panels, 6.85m for the closure panels and 6.45m for the remaining intermediate panels. Anticipated reinforcement requirements per panel would therefore range between 78t and 97t and concrete volumes, including estimated "over-break" between 400m³ and 470m³.

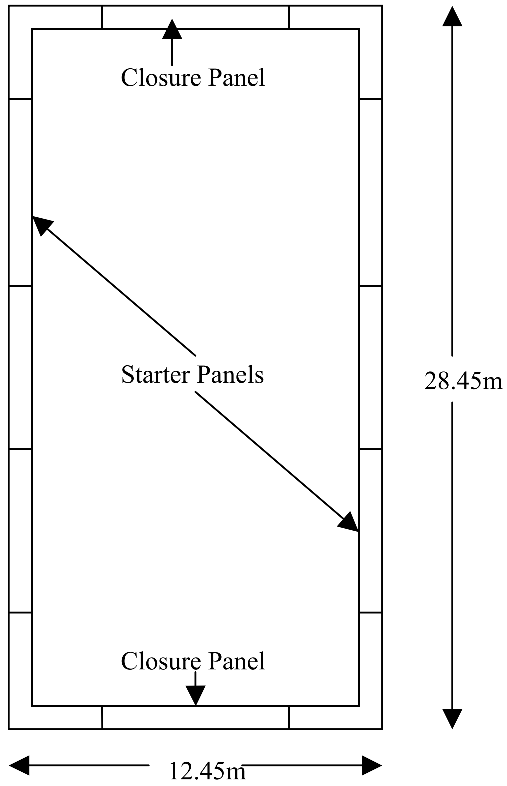

Fig. 1. Diaphragm wall panel arrangement.

Measures for Working Next to the Railway

With the decision made on the basic panel arrangement the next practical problem to address was how to operate next to the adjacent railway line. The principle requirement was that nothing must be allowed to encroach or fall within 2m of the nearest rail no matter how improbable the cause or unlikely the event. With one corner of the diaphragm wall being located only 5m from the nearest rail, compliance could be potentially difficult.

A "Safe Method of Working Statement" (SMOWS) was required to be developed and formally accepted by the relevant authorities before work could start. The primary concern would be the positioning and operation of the cranes. The work would require the use of up to 4 cranes; 2 crawler cranes for the hydro-mill and grab and two handling cranes for lifting and placing the reinforcement cages. To gain acceptance, drawings of every possible crane location and it's radius of operation, together with vertical sections showing boom lengths and possible collapse circles, were produced for each operation on every panel.

Even when it was demonstrated that the cranes could be sited such that in the event of failure they would not present a danger, additional measures were required to prevent operator error or mechanical failure causing the crane to work outside the stated limits. For the handling cranes it was decided to use Liebherr truck mounted mobiles, one of 180t capacity and one of 70t capacity. The advantage of these cranes is that they are equipped with the “Liccon” working area limitation system. This is a computerized control system that once set and locked prevents the operator from moving the boom outside the preset limits.

For the crawler cranes it was decided to use slew restrictors comprising an audible warning stage followed by an electronic cut out. If these failed or the crane kept slewing the final preventative measure was to be heavy duty sprung buffer plates fitted above and below the slew ring in such a manner that they would mechanically prevent the crane rotating past a predetermined point.

Loads that could topple into the danger area in the event of a failure of any lifting device were to be tied back by a steel cable running from a winch anchored down at the edge of the site farthest away from the railway. During lifting operations the cable was to be attached to the top of the load and kept semi taut.

Moving the machines into their predetermined set up positions was to be under the supervision of a qualified and approved Controller of Site Safety (COSS). This person was to be given absolute authority to stop the job if he considered the SMOWS was not being followed or indeed if he believed that there was any risk to the railway.

Reinforcement

Concurrent with the preparation of the SMOWS the detailed design and detailing of the reinforcement for the diaphragm wall was being carried out by CFSBSJV. The force diagrams and bending moment envelopes provided by the CTRL designers together with adherence to the specified design codes were producing average reinforcement requirements of about 250kg/m² and more for heavily loaded sections of the wall.

With this quantity of reinforcement maintaining sufficient space between bars to permit the free flow of concrete can become a problem particularly at splices. At one stage consideration was given to using 57mm diameter bars. However after reducing the clearance at the joints and between the 2 cages in the panel by as much as was considered practical, 50mm main bars at 160mm centres with links at 150mm vertical centres, on both faces, was the outcome in the most heavily loaded areas.

If cages were to be lapped together the specification required that alternate bars were to be staggered and that lap lengths were to be 60 times the diameter. This would have meant that splicing the sections together by lapping the bars would have stretched over a 6m cage length, an operation that is awkward, possibly dangerous, and certainly time consuming. It was therefore decided to splice the cage sections using a proprietary coupling system. Alternate bars would still have to be staggered but only by a nominal 0.5m.

The coupler selected was the Ancon CCL - BT type C system. In this system the end of each bar to be joined is cut square and enlarged by cold forging. This increases the core diameter of the bar to ensure that the joint is stronger than the bar. Parallel metric threads are cut onto the enlarged ends. The threaded end can then be proof tested to a force equal to the characteristic yield strength of the bar if required. The BT Type C system has an additional locknut and is used where the continuation bar cannot be rotated. The continuation bar is threaded for the full coupler length plus the length of the locknut.

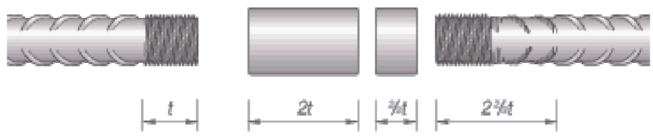

Fig. 2. Ancon CCL - BT Type C system.

The decision to use couplers initiated another problem to resolve. If the reinforcement bars are displaced, in any direction, by more than a few millimeters it is not possible to connect them. To prevent this, the cage sections would need to be coupled together during fabrication, the reinforcement bars would then need to be fixed rigidly in place and then the cage sections separated for transport to site.

In the UK it is standard practice to stiffen diaphragm wall cages, for lifting and placing in the panel, by welding some of the bar intersections with approved welding procedures. Even when this is done some flexing of the cage and slight movement of the bars can happen when the cage is lifted.

On the project over 200 couplers would be needed for each panel and some 2570 in total. It was therefore imperative to make sure that the cages were fabricated and welded to the highest standards. Ideally this would be done in a factory, not site, environment but such a facility, of sufficient size for several 53m long cages, within the London area would be both difficult to find and likely to be expensive. After some investigation the chosen solution was to have them built in a vacant factory, previously used for the manufacture of cranes, in Sunderland in the north east of England. Although this was nearly 300 miles away from the site the additional transport cost was offset by lower labor and overhead costs.

Excavation & Bentonite Arrangements

The soils at the site comprised some 25m of sands, silts and clays overlying a 20m thick band of Thanet Sand beneath which is chalk containing bands of flints. Thanet sand is very dense partially cemented silty sand. The material is too hard to be excavated with grabs but is readily removed with a hydro-mill.

The Contract specified verticality tolerance was a fairly standard requirement of 1:120. Given the 53m depth of the wall, the 150mm end tolerances we had allowed on the reinforcement cages and practical considerations such as removing the CWS joint former at this depth, 1:500 or better was really the target to achieve. With an experienced operator the hydro-mills can work to such standards.

Even when using a hydro-mill it is common practice to excavate the upper portion of the diaphragm wall with a grab. This provides the space and slurry reservoir that the hydro-mill needs before it can start. The grab is also often used for cleaning out the base of the panel prior to placing the reinforcement and for removing the CWS joint former. However a verticality of 1:200 is about the best that can be expected with this equipment even with an experienced operator. It was therefore planned to restrict grab excavation to a depth of only about 12m.

With the decision made to use large panels a bentonite slurry storage capacity of about 1200m³ would be required (roughly 3 times the average panel volume). Typically tanks or silos that are road transportable and have a capacity of 40m³ to 50 m³ are used. If space and circumstances permit lined storage pits are another option. At the Graham road site there was simply insufficient room to accommodate 20 to 30 tanks and pits were out of the question. The solution was to squeeze into the site 4 circular steel tanks 11m diameter and 3.6m high. These tanks have a concrete base and are built from prefabricated thin steel sheets bolted together on site. Three smaller 40m³ capacity tanks were also to be used as a water reservoir and for waste slurry storage.

In addition to the banks of hydro-cyclones and screens that are normally used for removing the excavated soil from the bentonite slurry it was decided to use a large centrifuge. Previous experience of using hydro-mills in Thanet Sand had shown that the fine silt element was not removed by the standard cleaning equipment which led to unacceptable thickening of the slurry. The centrifuge chosen had a variable speed bowl and was capable of processing up to 60m³ of slurry an hour.

Programme

The critical operations in the process were not going to be those involved with panel excavation but were the installation of the reinforcement and the concreting, both activities heavily dependent on outside suppliers. Detailed discussions were held with both the transport company delivering the cages and the concrete supply company. These discussions were not aimed at dictating the site requirements but rather at informing them of the importance of their performance and agreeing on the optimum method for achieving that performance. Both suppliers emphasized that a minimum of 3 days and preferably one weeks notice was essential. In addition the transport company did not favor a Monday delivery of the cages because of possible driver availability problems at the weekend and the concrete company did not favor Fridays for supply of the concrete because of increased traffic congestion on that day and possible driver availability problems if the pour ran late.

Following these guidelines meant that reinforcement could be placed on either a Tuesday or a Wednesday and concrete on a Wednesday or a Thursday. Clearly from this a schedule of one panel a week was the best that could be reasonably expected even though the hydro-mill was capable of producing up to double that amount of excavated wall.

CONSTRUCTION

Site Preparation and Guide Walls

The general preparation of the site and the construction of the guide walls were carried out by NCSJV, the main contractor. A 250mm thick reinforced concrete slab was put down over the access and working area to ensure stable platforms for the plant and equipment and facilitate the maintenance of a high standard of site cleanliness. The guide walls were the typical 1m deep reinforced concrete construction but in this case were tied into the concrete platform giving better security against movement during wall excavation.

NCSJV also arranged for the connection of the mains water supply and more importantly the temporary 850KVA mains electrical supply required to power the slurry cleaning equipment and pumps and minimize noise levels.

Bentonite Mixing, Cleaning and Storage

The four large bentonite storage tanks were erected by a specialist subcontractor. The mixing plant and powder silo for bulk bentonite storage were set up as was the Sotres slurry cleaning plant and the centrifuge. Distribution pipelines and pumps were established for the bentonite slurry and all the equipment had to be wired into the mains electrical supply. This establishment period took 3 weeks. The general arrangement of this equipment is illustrated in Fig. 3.

This sketch (Fig. 3.) also demonstrates the very limited space available on this site. The sketch does not show the 4 cranes nor the tracked excavator, small dump truck, panel joint formers, and other plant, equipment and spares that needed to be on the site.

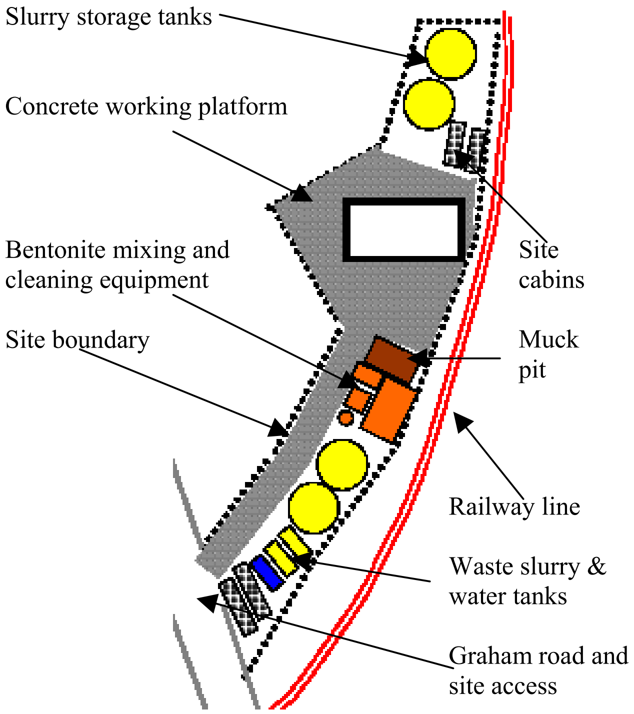

Fig. 3. Sketch showing arrangement of static plant. The 28m x 12m shaft helps demonstrate the size of the site and the area available for the work.

Diaphragm wall excavation

The excavation equipment selected, based on availability more than anything else, came from the Bachy Soletanche plant fleet and comprised; a rope operated grab suspended from a Liebherr 853 crawler crane, a Bachy Soletanche "Hydrofraise" mounted on a Liebherr 873 crawler crane and a Bachy Soletanche "Sotres" bentonite desanding and cleaning plant. The centrifuge, together with an operator, was sourced from an outside supplier.

The grab excavated the top 12m of the panel and the Hydrofraise then continued the excavation from 12m down to 53m. As well as the overlying clays, sands and silts the cutting heads on the Hydrofraise had to get through some 20m of hard Thanet Sand and then 10m into the chalk including penetrating through hard flint bands.

During excavation by the Hydrofraise the bentonite slurry was continually circulated through the Sotres and the centrifuge to remove the soil cuttings. A proprietary fluidifier and fluid loss reducer were used to maintain the desired properties but even with these the cleaned and treated slurry rarely had a specific gravity of less than 1.15 even though sand content had been reduced to less than 2%.

All excavated material was deposited into a 150m^3 capacity temporary muck pit on site. Before the excavated spoils could be transported off site they were treated with a combination of cement and gypsum. This process dried the material sufficiently to allow loading onto trucks for transport to Stratford in east London where the material, after further treatment, was used for the land raise works carried out under CTRL Contract 230.

On completion of excavation of a panel the slurry was completely exchanged with slurry that was only used for cage placing and concreting. This was done by the Hydrofraise pumping the slurry from the bottom whilst introducing the replacement slurry into the top of the panel.

The steel joint formers, including the continuous rubber water bar, were placed at the ends of the panel. These were installed in 12m and 6m sections and jointed together as they were lowered into the trench. The joint formers were suspended from the guide walls with the toe 2m above the bottom of the excavation. These formers were "peeled" away from the concrete of the finished panel on completion of excavation of the adjacent panel some days or weeks later.

Reinforcement

The delivery and installation of the reinforcement cages went smoothly. Four trailers, with two cages each, left Sunderland the day before they were required and parked overnight just outside London. The first trailer was brought to site at 8.00 a.m. the following morning with the remainder called in as required during the day.

The two bottom cage sections for each panel were lowered into the trench and supported from the guide walls. Subsequent sections were carefully lowered until the couplers aligned with the threaded bars at the top of the installed section. In case there were problems with connecting the couplers some 6m long splice bars were kept on site but were used on only two occasions during the project. In both cases this was due to misaligned bars not defects in the couplers.

On the 12 separate days when this operation was carried out the work was completed by the 6.00 p.m. deadline generally taking about 8 hours much as anticipated.

Total reinforcement placed in the 4120m^2 of wall was 1026 tonnes, an average of 249Kg/m^2.

Fig. 4. Photograph showing delivery and lifting of a reinforcement cage section. The Bachy Soletanche Hydrofraise is seen in the foreground.

Concrete

The diaphragm wall concrete was supplied by RMC Readymix from their Stepney plant backed up from their Canning Town plant. The concrete used was a 40N/mm² tremie mix retarded so that after 6 hours it still exhibited a slump of greater than 100mm.

Permission was obtained to work up to 10.00 p.m. on the 12 occasions required for this operation. This limit was never exceeded and on all but one occasion the work was completed before 8.00 p.m. Only 2 complaints, quickly and amicably resolved, relating to noise and disturbance were received throughout the course of the project, both from the same resident. Up to 12 trucks were used by the concrete company to meet the delivery requirements. As expected delivery rates were close to 50m³ an hour up to mid afternoon but then reduced to less than 30m³ an hour as traffic increased on the surrounding roads.

Slightly more than 5100m³ of concrete was used for the diaphragm wall against a theoretical volume of 4815m³, an "over break" of 6.25%.

Progress

Excavation for the diaphragm wall began two weeks later than scheduled due to factors unrelated to actual construction. This delay meant that at one panel a week the work would not be finished before the Christmas shutdown. This had serious financial and time consequences because to wind down and then restart such an operation could take between one and two weeks, depending on the construction cycle, in addition to the actual holiday period.

Once work started progress went as anticipated. The excavation of each panel was completed in sufficient time to meet each of the planned reinforcement and concrete delivery dates that had been scheduled at the outset and confirmed one week in advance. It was always a concern to the construction team that a problem might arise leading to the postponement of confirmed reinforcement and concrete delivery days. Any such postponement would then likely be almost a week rather than a day because of the notice necessary for the suppliers to rearrange their schedule.

About half way through the work confidence in the performance of everyone involved in the project was such that it was decided to pull back the time lost at the start, by concreting two panels in one of the remaining weeks thus completing the works before the holiday. To achieve this it would be necessary to pour concrete on a Saturday and for that special dispensation would need to be obtained from the relevant authorities. No doubt helped by the performance to date and the confidence this had engendered permission was obtained to work on a maximum of two Saturdays.

In the event both Saturdays were used to achieve two panels a week on two separate weeks thus completing the works early.

The Finished Wall

Shortly after completion of the diaphragm wall NCSJV began excavating the inside of the shaft. A top down method was employed incorporating 6 levels of permanent reinforced concrete props. On completion the wall was surveyed and found to be a maximum of 20mm out of vertical over the 47m depth exposed. The panel joints appear to be tight and properly formed and there are no inclusions, exposed reinforcement or other such imperfections that can occur with this form of construction if the work is not carried out by experienced personnel working to the highest standards.

Summary

This paper makes no attempt to describe the technical or design aspects of this project but seeks to describe the planning and project management that went into the successful completion of the work. The author considers it worthwhile to highlight the problems and some possible solutions to deep foundation construction on small urban sites.

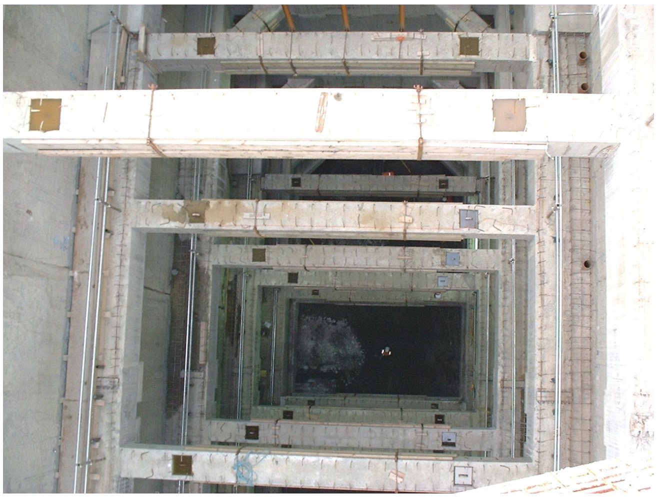

Fig. 4. & 5. Photographs taken during the 47m deep internal excavation of the shaft showing the shaft viewed from the surface and the diaphragm walls just above the maximum excavation depth.

More and more, in the major cities of the world, the specialist contractors are being asked to work within restricted working hours and maximum noise levels and yet they are expected to install deeper and heavier foundations. In the event this particular project was constructed to the highest standards, was completed early and below the target cost. However to achieve this some of the most experienced people in the business put a lot of thought and preparation into the planning process and ensured that the operatives assigned to carry out the work had the required level of expertise and competence.

Another major factor contributing to the success of the project was the nature of the contractual arrangement used on the CTRL projects and the unified project teams that resulted.

The author would like to thank; Steve Parker, RLE Contract Manager and Terry Macdonald, NCSJV Project Director and their staff for their cooperation and positive goal orientated attitude without which the work could well have foundered in the increasing volume of administrative and approval procedures that accompany the start of such major construction projects.

Fig. 6. Aerial photograph taken during shaft excavation showing the site's confined nature and residential surroundings.