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Building response to underground construction: the New City Court case history

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ABSTRACT: New City Court in Southwark, southeast London, was recently affected by the construction of London Bridge underground station during the Jubilee Line Extension Project. It consists of two separate but linked structures: a Victorian terrace and a piled 4-storey reinforced concrete framed office block. Protective measures, comprising compensation grouting within the underlying London Clay, were implemented from a temporary grouting adit adjacent to the Victorian terrace, to control the movements of the buildings during the underground construction works. The responses of the two structures, as well as the construction joint at their junction, to the various construction activities was monitored by a variety of methods, including precision levelling and crack measurement. The results of this monitoring together with contour plots of grout injection intensity are presented in this paper as well as a discussion of the observed responses of the structures. It is demonstrated that the compensation grouting protective measures controlled ground settlements such that the maximum building movements recorded were less than 35 mm.

1 INTRODUCTION

The £3.5 billion Jubilee Line Extension Project (JLEP), was the extension of London Underground's Jubilee Line from its station at Green Park in West London to Stratford, East London (Figure 1). Recently completed, the 15.5 km long Jubilee Line Extension (JLE) provides parts of south and east London with an efficient local transportation facility as well as connections to regional transportation networks. At London Bridge, the JLE underground station forms part of a complex transport interchange, which includes the existing Northern Line of the underground, the national/suburban rail network and local bus termini. The station is of the enlarged tunnel type and includes numerous shafts and connecting adits. At the surface, the London Bridge area comprises a dense and congested urban environment. This paper presents an account of the response of New City Court, 4-20 St Thomas Street, Southwark to the construction of the JLE London Bridge station, and, in particular, the structure's response to the various excavation phases and corresponding compensation grouting episodes that were implemented. The monitoring carried out by the contractor during the underground construction works included precision levelling and crack measurement. The results of this monitoring are presented and compared, and discussed in relation to the overall response of the structure.

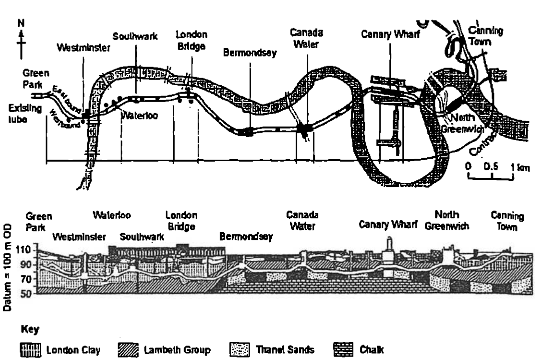

Figure 1. JLEP route and geology.

2 GEOLOGY AND GROUND CONDITIONS

The near surface geology of the London Basin comprises a broad synclinal (sagging) fold in the Cretaceous (Chalk) and overlying Tertiary sedimentary deposits. The Tertiary sediments are overlain by a mantle of Pleistocene sands and gravels, which, in turn, is capped by recent alluvial deposits and made ground (Figure 1). Episodes of fluvial and glacial deposition and erosion, have created a stratified geological section.

The ground in the vicinity of the JLE underground station at London Bridge is delineated by NE-SW trending faults. Some 70 m to the east of the station, a fault with a downthrow of about 6 m to the southeast intersects the JLE running tunnels. To the west of the underground station, another fault of similar displacement and orientation has been identified. This feature has been associated with the poor tunnelling conditions encountered during the enlargement of the adjacent City and South London Railway (which subsequently became part of the Northern Line) between 1922 and 1924 (Jones and Curry, 1927). The ground between these two geological structures forms a minor horst feature, which has marginally elevated the London Clay.

Groundwater is present within both the superficial deposits (i.e. the Terrace Gravels, alluvium and made ground) and at depth within the chalk and the permeable Tertiary sedimentary deposits beneath the London Clay (i.e. the Thanet Beds and lower granular sub-units of the Lambeth Group) - the upper and lower (deep) aquifers, respectively (Simpson et al., 1989).

At London Bridge, a layer of made ground typically 3 m thick, overlies a thin band of alluvium of the order of 1 m thick. Terrace Gravel deposits in excess of 7 m thick underlie these alluvial deposits, while stiff overconsolidated London Clay is encountered beneath the gravels, to depths in excess of 30 m. The units forming this stratified geological section are relatively uniform across the site. The water table in the overlying Terrace Gravels and other surficial deposits was generally found to be at approximately Ordnance Datum (i.e. between 5 and 6 m below the existing ground surface).

With the exception of the near-surface sections of the shafts and tunnels, excavation on Contract 104, London Bridge, was undertaken within the London Clay. A borehole log representative of the ground conditions for the area is given in Figure 2.

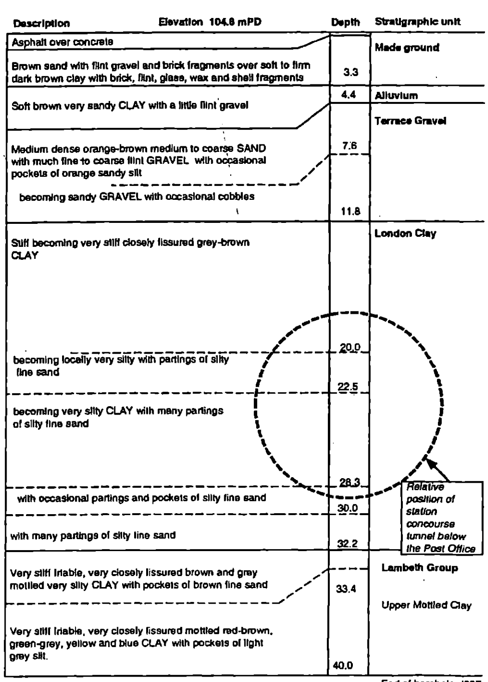

Figure 2. Summary log of borehole J307.

3 BUILDING DESCRIPTION

New City Court, 4-20 St. Thomas Street is located within the Borough High Street Conservation Area in Southwark, southeast London and forms part of a complex of buildings between St Thomas Street and Talbot Yard, including Kings Head Yard, which were constructed largely during the 1980s. It abuts the southern side of St Thomas Street and occupies the area between St Thomas Street and Kings Head Yard to the south (Figure 3). New City Court comprises two separate but linked structures: a Victorian terrace and a 20th century office block.

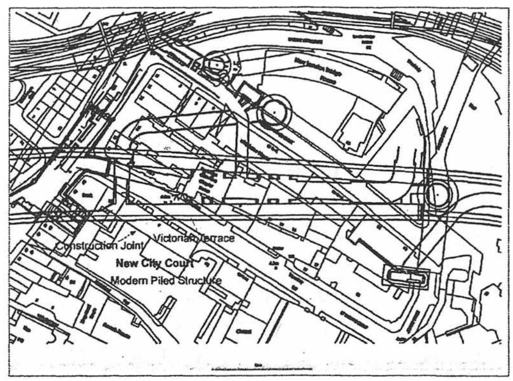

Figure 3. London Bridge.

The terrace abuts St Thomas Street and originally comprised a number of 3 and 4-storey Victorian town houses of varying configurations, Nos. 4-16 St Thomas Street (Figure 4). It is not known whether the town houses were all constructed simultaneously or, with the exception of the 1980s redevelopment and third storey addition to No. 16 St Thomas Street (it is thought that this storey was added to the town house some time after initial construction), if they have been significantly altered during their history. Along St Thomas Street, the terrace abuts The Bunch of Grapes Public House to the northwest, and the new office block to the southwest and southeast. The current buildings are about 12 m in height and form a regular rectangle in plan, approximately 42 m by 10 m. They consist of load-bearing, yellow brick masonry walls on corbelled brickwork strip footings. The strip footings bear on the underlying alluvium. The rear footings were underpinned using various combinations of brickwork and mass concrete, during the 1980s conversion works.

The north-facing, brickwork façade (i.e. that façade abutting St Thomas Street) and most of the original party walls adjoining it, appear to have been retained from the original terrace, although several doorways have been formed in each party wall. Externally, Nos. 4, 6, 8 and 12 St Thomas Street (there is no No.10) have gauged, flat, brick arches to sash windows in stucco-lined reveals, a moulded stucco cornice above second floor windows and a first floor stucco sill band. No. 14 St Thomas Street has a stucco frieze, cornice and blocking course, stucco sill band at first floor level and stucco string course at spring level of the ground floor round-arched window recesses. Similarly to No.14, No.16 St Thomas Street has a stucco frieze, cornice and blocking course, stucco sill band at first floor level and stucco string course at spring level of the ground floor round-arched window recesses. Such features, particularly the first floor level stucco sill band, were useful in detecting signs that the terrace had undergone past movement, including distortion of brick window arches and the tilting of some of the door lintels. Evidence of brickwork replacement has also been noted in this façade. The wall at the northwest end of the building is a party wall, shared with The Bunch of Grapes. The wall at the southeast end of the building and the entire rear façade, were rebuilt during the 1980s conversion. The original walls of the terrace comprise solid masonry whereas the new walls are of block/brick cavity construction.

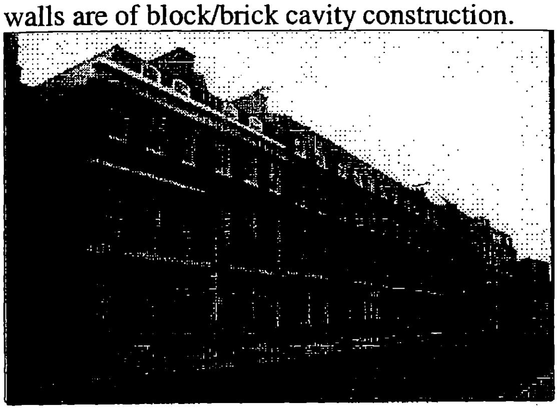

Figure 4. New City Court: Victorian Terrace.

In the mid-1980s the building was converted to offices and a large, irregularly-shaped 4-storey office block was added behind the original terrace as part of a general redevelopment of the area. It is extensive with frontages onto both Kings Head Yard and St. Thomas Street. The existing façade in Kings Head Yard was retained as part of the development. The structure is a purpose-built, brickwork clad, modern office complex consisting of a reinforced concrete frame supported by a piled foundation. The 450 mm diameter bored cast insitu reinforced concrete piles extend into the London Clay, terminating about 3 m above the crown of the westbound station tunnel (Figure 5). They are arranged in various configurations, from pairs up to a group of seven. All four levels of the new building connect through to their equivalent levels in the older terrace structure to the north, a full height movement joint having been formed at the junction between the old and new structures.

Both building condition and structural surveys of New City Court were carried out prior to the commencement of underground construction in the vicinity. As part of the building condition survey, a schedule of all existing defects of the structure, fixtures and fittings, was compiled. These surveys revealed that the structure of the building was in very good condition both externally and internally given the different types and ages of construction of the various parts of the building. Only very minor defects such as hairline cracking to plaster finishes were noted.

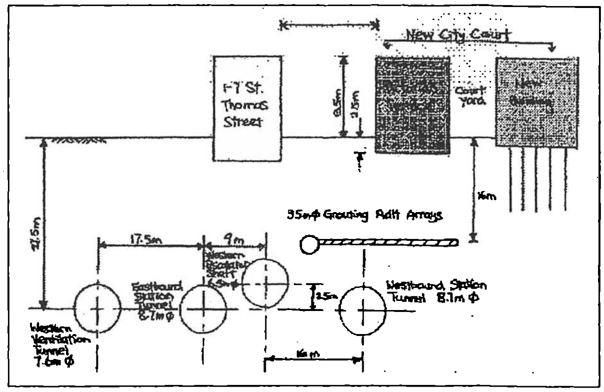

Figure 5. Profile illustrating the underground works.

4 CONSTRUCTION WORKS

New City Court was affected by several distinct but related construction activities, including
(a) the excavation of the compensation grouting adit in St Thomas Street, and subsequent installation of the tubes à manchette (TAMs);
(b) the excavation of the westbound running/station, concourse and Interlocking Machine Room (IMR) tunnels, and western escalator shaft, and
(c) the compensation grouting ground treatment works undertaken during underground construction.

4.1 Grout adit

To complete the TAM arrangement employed at London Bridge (see 4.3 below) a new, initially 1.96 m i.d. (internal diameter) increasing to 3.05 m i.d. adjacent to New City Court, temporary works tunnel was excavated beneath and parallel to St Thomas Street, from a breakout in the disused northbound City and South London Railway tunnel under Borough High Street (Greathead, 1896). This shallow, grouting adit was excavated by hand between 9 November and 20 December 1994 and lined with bolted precast concrete segments. On completion of ground treatment operations the adit and associated TAMs were backfilled to facilitate construction of the adjacent western escalator shaft.

4.2 Tunnelling works

The 8.7 m o.d. (outside diameter) westbound station tunnel, which traverses the northern half of New City Court (i.e. the Victorian terrace), at a skew of about 30° to the St Thomas Street façade of the building, was constructed using the Sprayed Concrete Lining (SCL) technique, adopting a combination of pilot tunnel and enlargement. The SCL technique essentially comprises the application of sprayed concrete (shotcrete) as initial (primary) support to sequential tunnel excavations. Small sections of the tunnel are systematically excavated, cut in benches if appropriate, followed by the rapid application of a flexible shotcrete support structure. Installation of the permanent (secondary) support system follows at a predetermined later date. It was envisaged that the pilot tunnels would act as large dowels, stabilising the excavated faces and limiting settlement during the subsequent enlargements (Mair, 1993). Pilot tunnels were driven for all tunnels larger than 8.2 m in diameter at London Bridge. The Type 4 cross-sectional detail for phased excavations (ICE, 1996) was used for both the 5.4 m o.d. pilot tunnel and subsequent enlargement, with 3.0 m heading and 2.4 m invert, and 3.5 m heading, 2.5 m bench and 2.7 m invert respectively. During enlargement of the station tunnel, the pilot tunnel was generally over-cut and its lining demolished with the advance of the excavation face for the finished tunnel. The exception to this was the reinforced concrete section cast within the invert of the pilot tunnel, which was subsequently incorporated into the invert of the enlarged tunnel.

The westbound running/station pilot tunnel drive was in the vicinity of New City Court from 25 April 1995, being directly beneath the structure between 1 May and 1 June 1995. During this time there was a temporary cessation of tunnelling for a period of about 3 weeks from 4 May 1995. The corresponding station tunnel enlargement works were undertaken from 5 September until 26 November 1995, being directly below the building between 7 and 29 September 1995. Average advance rates were 4.5 m/day and 1 m/day respectively for the westbound running/station tunnel pilot and enlargement works.

The 8.7 m o.d. east- and westbound station tunnels were excavated approximately concurrently, the excavation face of the westbound tunnel being some 40 m ahead of the adjacent eastbound tunnel, and as such any influence that the eastbound station tunnel excavations would have had on the response of New City Court would have been largely obscured by that of the nearer westbound station tunnel.

The 8.2 m o.d. IMR tunnel to the north of New City Court, which links east- and westbound running/station tunnels, was advanced from a break-out in the westbound station tunnel, also employing the SCL method and incorporating a phased full-face excavation, with 3.8 m heading, 2.9 m bench and 1.5 m invert respectively. The IMR tunnel drive took place during October 1995, with an average advance rate of 1.8 m/day.

As with excavation geometry, the thickness of the shotcrete temporary lining was dictated by tunnel diameter. It varied between 150 mm for the running tunnels, 300 mm for the station tunnels and 400 mm for the station concourse tunnel. In addition, all shotcrete sections were reinforced with mesh reinforcement and lattice girder arches, comprising three 12 mm to 16 mm diameter reinforcing bars, were installed for every 1 m of advance.

The 6.5 m i.d. (internal diameter) western escalator tunnel and 7.7 m i.d. Lower Machine Chamber (LMC), which link the Borough High Street Ticket Hall with the station concourse tunnel below, were both excavated by hand. The LMC essentially forms the transition between the western escalator and station concourse tunnels. The surficial ground to be excavated to form the western escalator tunnel (i.e. the Terrace Gravels and Alluvium) and the approximately 2.5 m annulus around it, was subject to permeation grouting. In excess of 475 m^3 of grout was injected during these ground treatment works, which preceded the main tunnelling works, being carried out between October 1995 and February 1996. This ground treatment reduced the permeability of the surficial soils, primarily the Terrace Gravels, as well as increasing their strength. These improvements made subsequent tunnelling easier, the soils being less susceptible to ravelling and the adverse effects of groundwater inflows. The western escalator tunnel was advanced in a downward direction, at an angle of approximately 30° to the horizontal, as a full face drive between 19 January and 15 April 1997.

4.3 *Protective measures*

Stage I assessments (Burland, 1995), made in the early 1990s by the technical contractor for the underground works at London Bridge, indicated maximum settlements of about 60 mm occurring within the footprint of this building for the then proposed JLE works, with a corresponding maximum building slope of 1:325 (V:H). New City Court was consequently classified for the purposes of potential damage assessment as Risk Category 4, High (Rankin, 1988). Compensation grouting protective measures were subsequently incorporated into the construction contract.

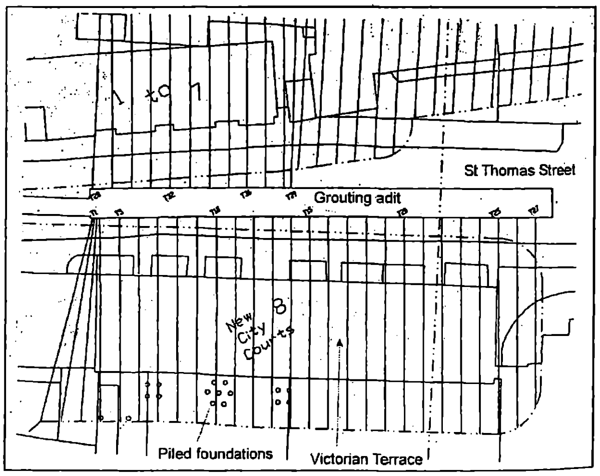

Figure 6. New City Court: TAM layout.

Unlike most compensation grouting TAM arrangements, which are radial in configuration, the TAM layout ultimately adopted at London Bridge was rectangular in nature (Figure 6). Although the existing subsurface environment, which was already heavily congested with tunnels (e.g.s the Northern Line and abandoned City and South London tunnels beneath Borough High Street, and the pedestrian subway underneath London Bridge Street) imposed severe constraints on the JLEP tunnelling works, their presence also provided ready-made facilities from which to carry out the compensation grouting operations. The temporary grout adit in St Thomas Street completed the rectangular TAM arrangement.

The TAMs beneath New City Court were installed between 2 and 24 February 1995, at a level of approximately 88 m.P.D., around about 6 m below the interface between the Terrace Gravels and the London Clay, while the depth of cover between them and the underlying tunnelling works was of the order of 5 m. They had a sub-horizontal orientation and were of the order of 20 m in length typically.

Compensation grouting was undertaken in the vicinity of New City Court between February 1995 and February 1997, with conditioning passes preceding the grouting works proper. The TAMs were conditioned between 24 February and 8 March 1995, a nominal 25 litres of grout being injected through a grout port during each pass, giving a total volume of grout injected of approximately 12,000 litres. In general during the compensation grouting works proper, 30 litres of grout was injected through each port selected for injection during any one particular grouting episode. Grout was transferred from the surface batching plant in St. Thomas Street to the adit below via a large diameter borehole. Over the course of the construction works, almost 95,000 litres of grout (this is equivalent to almost 100 m^3) were injected into the ground from the TAMs beneath New City Court.

In response to concerns for the stability of the excavation face and any unsupported lengths of tunnel during compensation grouting operations, when grout is being injected at relatively high pressure (i.e. of the order of 40 bar) close to the tunnel crown, an exclusion zone was incorporated into the ground treatment operations within the vicinity of all excavation faces. The injection of grout was not permitted within this zone, which encompassed both sides of and advanced with the tunnel excavation face.

The quantity of grout injected through each grout port beneath New City Court has been related to the corresponding building movement for each particular time interval under consideration through contour plots of grout injection intensity, defined as litres of grout injected per square metre of plan area (Vigianni, 2001). The unit of grout intensity is l/m^2, which also relates directly to mm of hypothetical heave.

5 INSTRUMENTATION AND MONITORING

The response of New City Court to the underground construction works was monitored primarily by precision levelling and crack measurement. The main contractor for the construction works at London Bridge, the Costain-Taylor Woodrow Joint Venture (CTW JV), undertook precise levelling surveys of points (i.e. small brass sockets and bolts) installed within the exterior walls of the buildings (Figure 7). Monitoring commenced in June 1994 and has continued until November 2001.

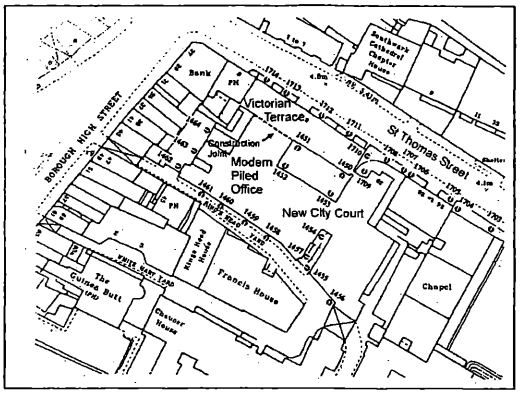

Figure 7. Precision levelling monitoring point locations.

During this time the monitoring frequency has been varied to take account of the ongoing construction activities (e.g. tunnel excavation phase, compensation grouting episode). On completion of underground construction and into the long term, the monitoring frequency was gradually reduced from, typically, a weekly basis to initially monthly and then six monthly. The displacements recorded during the precision level surveys have been evaluated relative to base readings taken before any construction works commenced in the area.

Avongard tell-tales installed at the junction between the Victorian and 20th century structures facilitated crack measurement. A total of 10 tell-tales were installed at various locations, both internally and externally, from lower ground up to third floor level during March 1995 and regular measurements made from this date up until the Summer of 2000.

The monitoring was undertaken using, where appropriate, state-of-the-art equipment, and employing best practice techniques throughout to obtain high quality data (Standing et al., 2001).

6 BUILDING RESPONSE

Given the complexity and duration of the construction works undertaken at London Bridge, the monitoring results are discussed in an overall sense in relation to the various excavation works and ground treatment operations, and corresponding building responses, with particular aspects of this response being highlighted. Three construction/monitoring

periods have been selected for closer consideration, namely the
(a) westbound running/station pilot tunnel drive;
(b) westbound station tunnel enlargement and IMR tunnel advance, and
(c) western escalator shaft excavation.
Results from the precision levelling surveys are presented first followed by the corresponding incremental grout intensity contour plots and lastly some crack monitoring data.

6.1 *Precise levelling*

Precise levelling data for points installed in the external facades of New City Court have been plotted against time for the entire monitoring period (Choy, 2001). Although troughs and peaks, corresponding to excavation phases and grouting episodes respectively, are evident throughout the construction period downward vertical displacement is dominant. Profiles of the changes in level of the various monitoring points situated along the facades of the buildings of New City Court as well as sections through these structures have also been compiled for the designated construction/monitoring periods. Figure 8 illustrates the response of the north-facing façade of the Victorian terrace, which is closest to the tunnel excavations, to the westbound running/station tunnel drive. The skew of this tunnel, and the corresponding enlargement, with respect to New City Court is such that its axis moves eastwards by approximately 27 m as it passes from beneath the rear, south-facing façade to below the front, north-facing façade of the terrace. The north-facing façade responded in a relatively rigid manner to the pilot tunnel drive and associated compensation grouting ground treatment operations (see below), which were approximately coincident with the location of the tunnel excavation works. The magnitudes of both the settlement and heave observed were small, less than 5 mm, as were the corresponding building slopes and deflection ratios. A similar response was noted for the south-facing façade, the magnitudes of settlement and heave being even less, suggesting, when coupled with the crack monitoring data (see below), that the Victorian terrace was, in part, rotating about a plane adjacent to the junction between it and the modern office block.

The enlargement of the station tunnel and the IMR tunnel drive resulted in larger movements being recorded (Figure 9). They were also generally consistent with the areal distribution of the excavation works and ground treatment operations in progress at the time (i.e. concentrated within the western half of the Victorian terrace). Overall the response of both structures, the Victorian terrace and the modern office block to the south, remained relatively rigid during this time with correspondingly shallow building slopes and small deflection ratios.

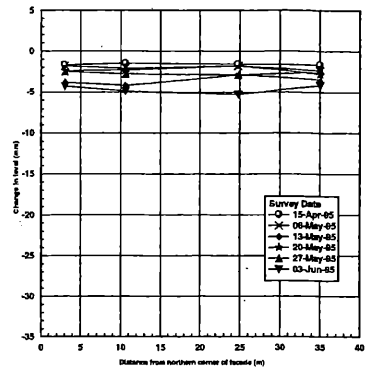

Figure 8. North-facing façade settlement profiles (April-June 1995).

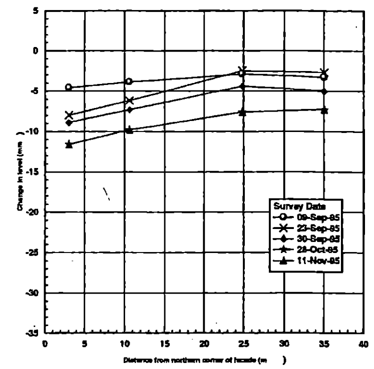

Figure 9. North-facing façade settlement profiles (September-November 1995).

Figure 10 shows the settlements observed for a section taken through both the Victorian terrace and the modern office block to the south during this period. It has been assumed in this case, given the nature of the crack movement observed at the junction between the old and new structures together with the type of foundation provided for the former, that linearly varying profiles can be constructed for sections taken at right angles through the buildings. This figure suggests that the modern piled structure is undergoing some form of rotation about a point to the south, maximum downward vertical displacements of the order of 10 mm being recorded adjacent to the junction between this building and the Victorian terrace, with both structures tilting towards the underground works.

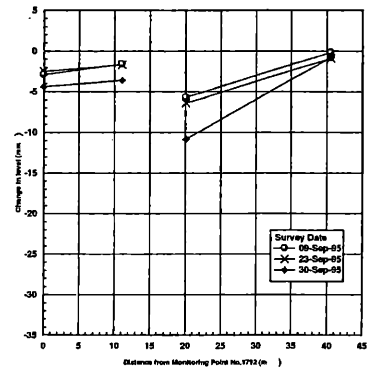

Figure 10. Section through New City Court.

Over a year passed before the western escalator shaft was then excavated adjacent to New City

Court. The underground works completed in the interim were relatively distant from the buildings and the corresponding settlements generally uniform in nature indicating that the dominant influence during this period was consolidation settlement of the recently disturbed ground. This consolidation resulted in settlements approaching 30 mm being observed along the north-facing façade of the Victorian terrace prior to the excavation of the western escalator shaft, more than the total settlement recorded following the enlargement of the running/station tunnel pilot, and resulting in the enlargement of the surface settlement trough (Note: this simple comparison does not take into consideration the ground treatment works that were carried out during running/station pilot tunnel enlargement and the heave subsequently induced). In addition, the corresponding building slopes and deflection ratios remained small. This is not unexpected as it has been shown that long term, consolidation settlements usually occur over a much wider area than those attributable to volume loss (i.e. immediate tunnelling-induced ground subsidence).

Excavation of the western escalator shaft resulted in further, generally uniform settlement of between 5 and 10 mm throughout the length of the north-facing façade of the Victorian terrace (Figure 11). The relatively long construction period, approximately 3 months, would have contributed to this response. At the end of construction building slopes of about 1 in 800 and deflection ratios typically less than 0.01 % were observed for the buildings of New City Court.

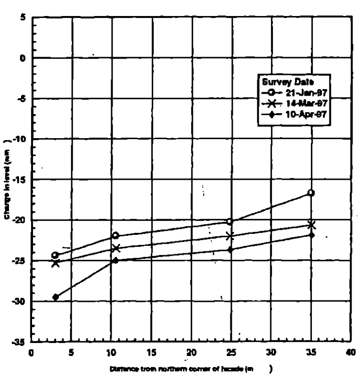

Figure 11. North-facing façade settlement profiles (January-April 1997).

Differentially, relative movement is greatest along sections through the Victorian terrace/modern office block, although the magnitudes of the differential settlements being recorded are offset by the nature of the building responses (i.e. tilting towards the underground works).

In the long term, generally uniform, progressively decreasing, downward vertical movements, corresponding to continuing consolidation settlement of the ground, are evident from the monitoring data, with values approaching 35 mm some 2-3 years after completion of the underground works.

6.2 Compensation grouting

Compensation grouting operations were only carried out beneath the Victorian terrace of New City Court. The ground underneath the modern piled office block was not subject to any specific ground treatment. The compensation grouting protective measures employed at New City Court can be split into three categories, namely

(a) conditioning;
(b) concurrent, and
(c) corrective grouting phases.

Conditioning grouting was undertaken in advance of the tunnelling works while concurrent grouting was carried out approximately coincident with underground excavation. The primary purpose of the former was to prepare the TAMs and adjacent ground for the grouting works proper and ensure that the monitoring equipment was fully functioning. Consequently, the areal distribution of the grout injections was quite general and only small movements were observed.

A little over 6,000 litres of grout was injected into the ground beneath New City Court during the westbound running/station pilot tunnel drive (Figure 12). It was concentrated in the northern half of the building footprint, at the junction between the Victorian terrace and the Bunch of Grapes Public House.

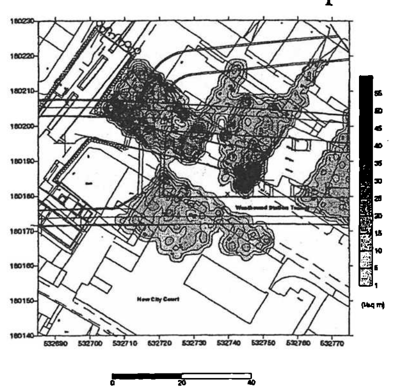

Figure 12. Grout intensity contour plot: running/station pilot tunnel drive.

The most significant concurrent grouting episodes were undertaken during September and October 1995, when both the westbound station tunnel enlargement and the IMR tunnel excavations were completed (Figure 13). During this period a total of almost 41,000 litres of grout was injected into the ground from the TAMs beneath New City Court. Grout injections were concentrated adjacent to the ongoing tunnelling works throughout this period.

Given that the Victorian terrace of New City Court runs obliquely to the axis of the westbound running/station tunnel it is interesting to note the limited differential settlement recorded along the north-facing façade of this building. This is largely the result of the compensation grouting ground treatment operations in the area.

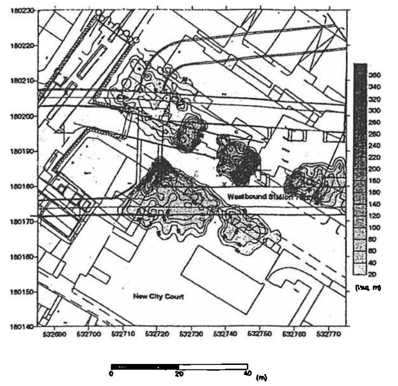

Figure 13. Grout intensity contour plot: westbound station tunnel enlargement and IMR tunnel drive.

A grout injection equivalent to 1 litre/m^2 might, in theory, result in a corresponding heave of 1 mm, assuming that:

(a) the grout only influenced the column of soil directly above the point of injection;

(b) the column of soil was incompressible and;

(c) the grout was not subject to shrinkage.

In practice the grout injected into the ground influences a wider area than just the soil column directly above it, the ground is not incompressible and the grout is subject to shrinkage. Consequently, the heave observed due to grout injection is less than in the idealised case. Nevertheless, overall grout intensities in the vicinity of New City Court during the construction period are typically of the order of 100 litres/m^2, and up to a maximum of 200 litres/m^2 locally. This would correspond to a heave of the order of 45 mm, assuming a best estimate of grout efficiency for this area of 45 %.

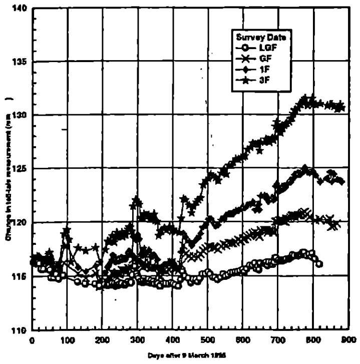

Figure 14. Crack measurement data: lower ground, ground, first and third floor levels.

6.3 *Crack monitoring*

Crack measurement data from the tell-tales installed at various levels up the junction between the Victorian terrace and modern office block of New City Court have been plotted against time for the entire monitoring period (Figure 14). As was evident with the precision levelling results, peaks and troughs, corresponding to the opening and closing of the movement joint during excavation phases and grouting episodes respectively, are also evident from the crack measurement data. And similarly with the precision levelling data, overall, downward vertical displacement (i.e. the opening of the movement joint) is dominant. As expected the magnitude of these movements increases with increasing height.

The first significant openings of the cracks being monitored, were recorded during the running/station tunnel pilot drive, with the cracks on the ground, first and third floors opening up by between 1 and 3 mm respectively. During the enlargement of this pilot tunnel and excavation of the western escalator further opening up of the joint was observed.

By the end of construction crack widths (i.e. the opening up of the movement joint) in excess of 15 mm had been observed.

6.4 *Reported damage*

Overall, Category 2, 'Slight' damage (BRE, 1995) was recorded for New City Court as a result of the JLEP works. It was concentrated at the movement joint between the Victorian terrace and the modern office block, and considered to be the result of the relative proximity of the underground works to each structure as well as the differential movement resulting from the different building foundation types (i.e. strip footings and piled foundation).

7 CONCLUSIONS

This paper has presented the results of some of the monitoring undertaken at New City Court, St Thomas Street, London Bridge during the JLEP underground construction works, which included running/station tunnel construction and compensation grouting ground treatment operations. The maximum observed building settlements and corresponding façade slopes were, at 32 mm and about 1 in 800 respectively, significantly less than those predicted adopting 'greenfield' conditions. In addition, only 'slight' damage (BRE, 1995) was reported to the buildings as a result of the JLEP. It was concentrated at the movement joint between the Victorian terrace and the 20th century office block. The compensation grouting protective measures have thus proved successful in controlling the tunnelling-induced movements of New City Court. This case study is another example of good workmanship and construction control resulting in limited building movements and subsequent damage. Furthermore, longer term monitoring has revealed that as with other buildings affected by the JLEP works (e.g. Viggiani and Standing, 2002) settlement becomes relatively uniform following completion of construction, the areal extent of the settlement trough increasing but the building slopes and deflection ratios remaining largely unaltered. The nature of the settlements and building responses observed are consistent with what one would expect given the foundation types (i.e. strip footings for the Victorian terrace and a piled foundation for the modern office block). The relative magnitudes of these settlements are, however, complicated by the relative proximity of the underground works and the protective measures employed.

Finally, this case history is an addition to the relatively sparse database of published records on the response of buildings with piled foundations to tunnelling-induced ground subsidence (e.g.s Lee et al., 1994, Forth & Thorley, 1996, and Geilen & Taylor, 2002).

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