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Assessing the historic movements of buildings - two case studies from the Jubilee Line Extension Project

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ABSTRACT: There are several well-documented methods for predicting potential building damage caused by underground excavation (e.g. Burland, 1995). In these methods it is generally assumed that the buildings are initially horizontal and have not undergone previous movement. Buildings where it is considered that damage might occur are usually subject to condition and defect surveys prior to the commencement of any underground construction works in the vicinity, to assess their current state in a qualitative manner. Only in exceptional cases are the buildings surveyed accurately to assess whether they have undergone any significant previous movement (e.g.s Anketell-Jones, 1998 and Anketell-Jones & Burland, 2001). Potentially, such deformation could have a significant influence on the way the building behaves when it is subjected to further movement. This paper presents the results of retrospective historical surveys on two buildings at London Bridge, Southwark, southeast London and discusses the deduced past movements in relation to the responses of the structures to the recent Jubilee Line Extension Project underground works.

1 INTRODUCTION

Although the methodology and procedures to be adopted when assessing the potential for damage to buildings due to underground construction are well-established (e.g. Burland, 1995), the influence of historical movements on such potential deformations is rarely taken into account as part of this process. The assumption usually made is that the building lines and subsequent settlement profiles are commencing from an apparent null point, i.e. the buildings are essentially horizontal. Rarely are the buildings accurately surveyed to assess the level of previous movement. Such historical deformations could, potentially, have a significant influence on the way in which the building responds to further movement (e.g.s Anketell-Jones, 1998 and Anketell-Jones & Burland, 2001). The following retrospective case studies from the recently completed Jubilee Line Extension Project (JLEP) further illustrate the importance of considering such historical effects in the damage assessment process and discusses these movements in relation to the subsequent movements which resulted from the Jubilee Line Extension (JLE) underground construction works at London Bridge, Southwark, southeast London.

The £3.5 billion 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). At London Bridge, a complex arrangement of tunnels, shafts, adits and passageways

was excavated to form a new underground station (Figure 2). The 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 terminus. At the surface the London Bridge area comprises a dense and congested urban environment.

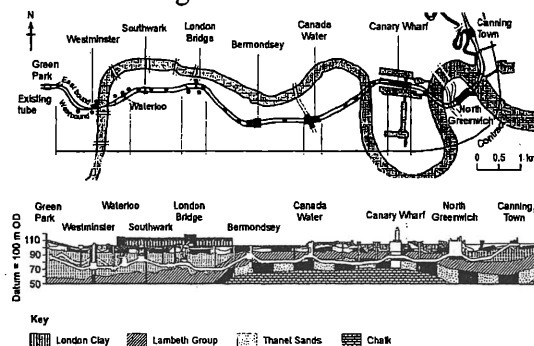


Figure 1. The JLEP: route alignment and geology.

Many of the buildings in the vicinity of these works are of historic significance, sensitive fabric or complex structure, and in numerous instances their proximity to the sub-surface works resulted in potential damage assessments being undertaken. The recommendations of these assessments lead to the incorporation of protective measures, including permeation and compensation grouting, into the construction contract for the JLE underground works to prevent significant damage occurring. In this paper two buildings, London Bridge Post Office and Tele-

phone House, which were affected by the construction of the JLE London Bridge underground station, have been reconsidered with regard to historic movement, its location and nature, and subsequent influence on the responses of these structures to the more recent tunnelling-induced ground subsidence. Both buildings are situated directly above the underground station and were part of the Imperial College LINK CMR (Construction, Maintenance and Refurbishment) research project (Burland et al., 1996)

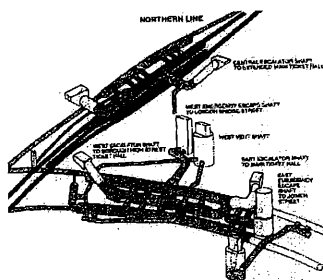


Figure 2. London Bridge underground station.

2 LONDON BRIDGE

The Southwark area of London, on the south bank of the River Thames has a long history of habitation dating from Neolithic times. The London Bridge area has served as a major crossing point on the River Thames for much of its history, various bridges having been constructed here, linking London to the South Bank and beyond. At one time large parts of Southwark adjacent to the River Thames were marshy. Drainage channel sand revetments were subsequently constructed to reclaim this land, particularly in what is now the St Thomas Street, Joiner Street and Guy's Hospital area (Figure 3).

Up until the early nineteenth century, when it was largely demolished to make way for the present railway station, around about the same time as the London Bridge of 1176 was replaced, St Thomas's Hospital had, since its creation in the 12th Century, occupied much of the area in and around what is now the London Bridge national/suburban railway station. Much of the area now bounded by London Bridge Street, Joiner Street, St Thomas Street and Borough High Street (the London Bridge 'block' of buildings) originally formed part of the hospital until its relocation to Lambeth in 1862 as a consequence of the expansion of the surface railway network in the London Bridge area. Of the original medieval layout of the hospital, only the Southwark Cathedral Chapter House (No.9a St Thomas Street), Collegiate House (No.9 St Thomas Street) and Mary Sheridan House (No.15 St Thomas Street) remain today together with the southern wing of the Victorian-era raised courtyard, London Bridge Post Office

(No.19A Borough High Street). Following the industrial revolution and associated urban expansion of the late 18th/early 19th century the face of Southwark was transformed. The existing London Bridge was replaced, new roads and railways constructed, and many factories and warehouses built during this period of explosive growth in population and industry. Following the acquisition of the land and buildings occupied by St Thomas's Hospital at London Bridge by the railway companies in the early 1860s, the area was redeveloped, and the adjacent surface rail terminus and approach roads, including London Bridge Street (Denman Street as it was then known), constructed. Due to the level difference between the railway station and surrounding urban landscape, the approaches were elevated structures, London Bridge Street being supported by a series of brickwork arches. The longitudinal axes of the arches are approximately perpendicular to the building facades that line London Bridge Street.

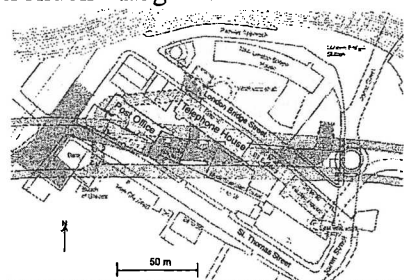


Figure 3. London Bridge.

The brickwork arches, founded on approximately 2 m wide by 1 m deep brick strip footings, rise up from original ground surface level at London Bridge Street's junction with Borough High Street, to a maximum height of about 8 m at the entrance to London Bridge mainline/suburban railway station, some 150 m to the east. When first built, the arch structures were wider than they are today, extending to the south into what are now the building footprints of Telephone House (10-18 London Bridge Street), the BT Building (20-26 London Bridge Street) and Fielden House (28-30 London Bridge Street). At present, the brickwork arches end about 1 m to the north of these buildings. The remnants of the foundations of these brickwork arches were encountered underneath the BT Building during the JLEP, while excavation in the basement of Telephone House revealed backfilled brick vaults below the building's sub-basement.

In addition to these sub-surface features, an existing (abandoned), approximately 3.5 m i.d. (internal diameter) pedestrian access tunnel, also known as the long subway, which at one time linked the existing Northern Line underground railway, beneath Borough High Street, with the adjacent mainline/suburban railway station, runs beneath and ap-

proximately parallel to London Bridge Street at a depth of approximately 23 m below existing ground level. This access tunnel was opened for service during December 1901 (Lee, 1967). Street access shafts associated with the adjacent Northern Line and situated on the northern side of London Bridge Street, connect into the long subway to the west of Telephone House. There is a further tunnel in the vicinity, about 3.0 m i.d. and also situated beneath and aligned approximately parallel to London Bridge Street, which runs from outside Telephone House, westwards to London Bridge Street's junction with Borough High Street. This tunnel is located above the long subway some 9 m below London Bridge Street, and served as an access to the original, now abandoned, City and South London Railway (C&SLR) tunnels, which run underneath Borough High Street to the west, and were used as an air-raid shelter during the Second World War. The first 35 m of this access tunnel was backfilled with mass concrete during the late 1950s/early 1960s. The original C&SLR tunnels had been abandoned in 1900 when a revised alignment between Borough and Moorgate stations was opened (Lee, 1967).

3 GROUND CONDITIONS

The ground in the vicinity of the JLE London Bridge underground station 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 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 (now 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.

Several boreholes were sunk within the London Bridge area as part of the JLEP site investigations. The corresponding borehole logs indicate that relatively uniform depths of made ground, alluvium and the Terrace Gravels overly the London Clay, the youngest of the Tertiary sediments, and in which the underground works are largely located, which in turn overlies the upper mottled clay of the Lambeth Group.

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). These two water-bearing horizons are commonly referred to as the

upper and lower (deep) aquifers, respectively (Simpson et al., 1989). Water has been abstracted from the deep aquifer for many years. In recent years, however, there has been a decline in such water abstraction and as a consequence groundwater levels in the Central London area are now rising, in some areas by as much as 1.5 m/year. Previously, water abstraction had resulted in a depressed piezometric level in this area of London. During the JLEP the water table in the overlying Terrace Gravels and other superficial deposits was generally found to be at approximately Ordnance Datum (i.e. between 5 m and 6 m below the existing ground surface).

4 BUILDING DESCRIPTIONS

4.1 *London Bridge Post Office*

The Post Office, 19A Borough High Street, is located on the eastern side of Borough High Street between its junctions with St. Thomas and London Bridge Streets, within the Borough High Street Conservation Area. The building itself is set back some 10 m from Borough High Street, being situated within the London Bridge 'block' of buildings (Figure 4). This 'block' of buildings is located directly above the JLE London Bridge underground station. It is understood that the basement of the Post Office building extends northwestwards beneath the 'open space' between it and Borough High Street. The Post Office building is generally surrounded by other structures of varying age, size and construction within what is a dense urban environment.

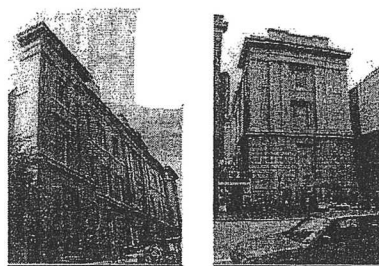


Figure 4. Views of London Bridge Post Office: Upper from Borough High Street, Lower from London Bridge Street.

London Bridge Post Office is a Grade II listed building and was constructed in the early 1840s by Samuel Grimsdell as part of a redevelopment of St Thomas's Hospital. It formed the southern wing of a new raised courtyard within the hospital complex (Figure 5). This configuration was similar to the original medieval layout of the hospital buildings. The Post Office is one of the few buildings remaining today that was once part of St Thomas's Hospital's London Bridge complex.

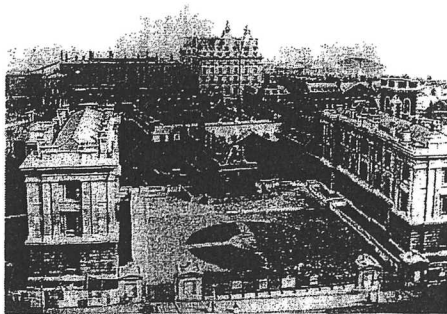


Figure 5. St Thomas's Hospital (with London Bridge Post Office in the extreme right hand side of the picture).

It is a 5-storey building approximately 16 m in height, which forms an irregular rectangle in plan, measuring approximately 38.0 m by 13.5 m, and comprises load-bearing brick walls, that are generally clad in limestone ashlar blockwork in classical Greek style. The exception to this is the exposed upper portion of the southeastern elevation, which consists of fair-faced brickwork. To maintain the symmetrical configuration of the original raised courtyard, the southeastern corner of the building consists of a narrow "nib-like" structure. It is thought, given the age of the building, that lime mortars would have been used in the construction of these walls, which would make the building more tolerant to subsequent settlement than its more modern counterparts. The binders in mortars have traditionally comprised either lime or cement. Pure lime mortars are relatively weak while pure cement mortars may, in fact, be stronger than the stone or brick bedding on it (IStructE, 1996). Any cracks in the masonry may go through the stone or brick rather than follow the jointing pattern if the mortar is too strong. The blockwork cladding is understood to be between 100 mm and 120 mm thick and attached to the underlying brickwork by ferrous metal cramps clipped to the masonry with mortises. Internally, with the exceptions of the basement and the main stairwell, the building is largely free of load-bearing walls or columns.

The foundations of the Post Office are understood to comprise a stepped raft made of a mix of one part of lime to six parts of gravel, which bears directly onto the Terrace Gravels. The building has a single-storey basement consisting of brick-lined vaults.

4.2 Telephone House

Telephone House, 10-18 London Bridge Street was constructed in 1915 and is understood to have been one of the first purpose-built telephone exchanges within the London area. It comprises a seven-storey structure approximately 20 m in height, and forms an irregular rectangle in plan, approximately 66.5 m long by 13.5 m wide. The building is clad largely in clay brick. The exceptions to this are the ground

floor elevation, the window sills and lintels of subsequent floors, and fourth floor and parapet roof level stringlines of the front, north-facing facade, which are all clad in limestone ashlar blockwork (Figure 6). During the JLEP, the rear, south-facing facade was clad largely in sand/lime bricks.

Telephone House is a hybrid type of structure with the floors comprising reinforced concrete beam and slab construction supported by a combination of solid masonry walls, reinforced concrete columns and concrete encased steel stanchions. The external, perimeter masonry walls and two of the interior brickwork walls, typically about 300 mm thick, are load-bearing as are the steel columns encased in concrete (these replaced some of the other original, internal load-bearing walls).

The foundations of the structure comprise reinforced concrete strip footings, typically 0.8 m deep and varying between 0.8 m and 1.1 m wide, bearing on the Terrace Gravels. The load-bearing walls extend down to a depth of approximately 2.1 m below the sub-basement, where they rest on the strip footings. On exposure, both the sub-surface brickwork and underlying foundation were found to be in good condition.

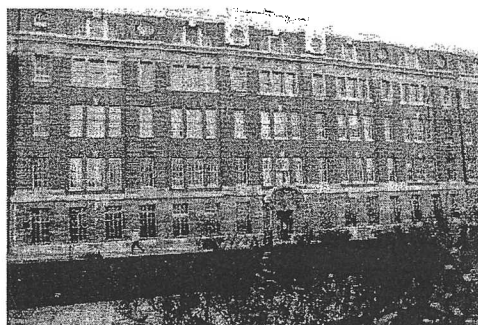


Figure 6. Telephone House (London Bridge Street facade).

5 FIELDWORK

During the construction of the JLE at London Bridge the response of the buildings in the vicinity of the works to the tunnelling-induced ground subsidence was monitored by the main contractor, Costain-Taylor Woodrow Joint Venture (CTW JV), primarily by precision levelling of points installed in the facades of the surface structures. CTW JV used state of the art equipment and employed best practice techniques to obtain high quality data (Standing et al., 2001). The displacements recorded during the precise level surveys have been evaluated relative to base readings taken before any construction works commenced in the area. Monitoring commenced in July 1994 and continued until December 2001 (selective points only).

No surveys were undertaken in advance of JLE underground construction at London Bridge to de-

termine the extent of historical movement in any of the buildings. Precision levelling adopting the same procedures, and using similar equipment, as was employed during the JLEP, has recently been carried out along stringlines and brick courses in an attempt to quantify this effect.

6 HISTORICAL MOVEMENTS

For the purposes of these investigations it has been assumed, given the type and quality of finish of the buildings under consideration, that the initial building lines (i.e. brick courses and stringlines) would have been approximately horizontal and that any difference between the present day stringline profile and the profile of adjacent monitoring points (installed within the building facades as part of the JLEP) following completion of the JLE, is indicative of past differential settlement. Historical movement has thus been deduced from the difference in levels between the retrospective stringline surveys and the long term JLEP monitoring data.

6.1 London Bridge Post Office

A comprehensive timeline covering the period of JLE subsurface construction has been compiled for London Bridge Post Office (Petrova, Standing & Taylor, 2002). Recent stringline surveys now allow the effects of historical settlement on this building to be quantified. These surveys suggest that the present stringline is effectively horizontal. Figure 7 shows the change in level along a stringline on the north-facing, longitudinal facade of the building, inferred from adjacent monitoring points, due to the JLE together with the pre-JLEP stringline profile (Note: It was not possible/worthwhile to survey other facades of this building due to logistical difficulties/intervening buildingworks). It is interesting to note that the JLEP works seem to have 'righted' the building, the present building lines being approximately horizontal. Prior to construction of the JLE London Bridge underground station the building appears to have been tilting in an approximately westerly direction. In consideration of past subsurface works in the area, particularly the C&SLR/Northern Line, such behaviour is not altogether unexpected. In general, the historical settlement profile is linearly-varying in nature. The maximum deflection ratio (sagging) for the historical settlement is less than 0.01%, suggesting a level of historical damage of '0', negligible (BRE, 1995). The pre-construction defect and condition surveys are generally consistent with such a level of previous damage. The damage

to the Post Office recorded during the JLEP was concentrated in the eastern end of the building.

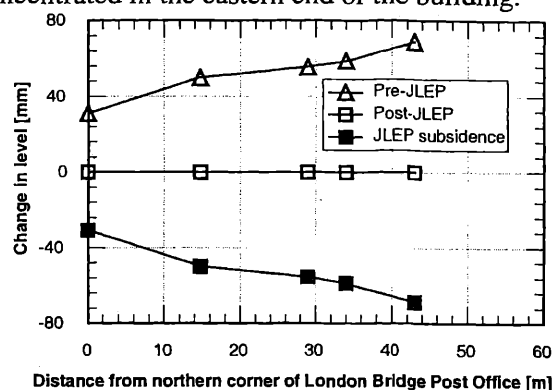


Figure 7. Inferred profiles of north-facing façade, London Bridge Post Office.

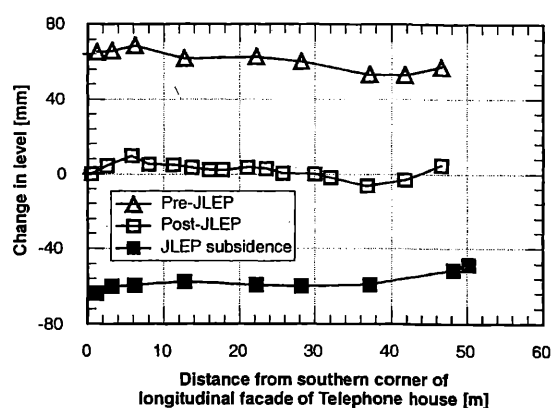


Figure 8. Inferred profiles of north-facing façade, Telephone House.

6.2 Telephone House

As with London Bridge Post Office, a complete timeline for the period of JLE underground works in the vicinity has been prepared for Telephone House (Geilen & Taylor, 2002). Following recent retrospective surveys the effects of historical settlement on this building can also be quantified. Figure 8 shows various profiles along the north-facing, longitudinal facade of the structure (Note: It was not worthwhile to survey other facades of this building as following completion of the JLE the building was sold and refurbished). The stringline surveyed is adjacent to the levelling points which were installed to monitor the response of the building during the JLEP. Comparison of the various profiles reveals that in general the profile of JLEP tunnelling-induced ground subsidence is similar in nature to the post-construction stringline survey, suggesting that this structure started from an approximately null (or horizontal) point prior to JLEP construction in the area. This is in contrast to London Bridge Post Office. The damage recorded at Telephone House during the JLEP was concentrated at structural discontinuities - the interface between Telephone House and the adjacent brickwork arches of London Bridge

Street - and at the focus of settlement, the southern corner of the longitudinal façade of the building. The existing tunnels running beneath and approximately parallel to London Bridge Street, the excavation of one of which preceded construction of Telephone House, do not appear to have had a significant effect on deformation historically.

7 CONCLUSIONS

The simple case studies presented in this paper have further demonstrated the importance of assessing historical movement within buildings, which are to be subject to subsequent tunnelling-induced ground subsidence. Not only do such assessments provide information on the deformation characteristics of the structure under consideration they also give indications of the residual settlement capacity that the building retains as well as providing details of potential weak points and where further movement is most likely to propagate. Furthermore, both retrospective case studies illustrate the value in completing a thorough desk study/archival research in advance of construction.

It is recommended that such simple investigations are carried out for all buildings of historical significance, sensitive fabric or complex structure when planning sub-surface works. The findings of such studies can serve not only as a basis from which potential damage assessment can be undertaken but also help indicate the most likely places where such damage will manifest itself.

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