London - Applied geology

From Earthwise
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Geological factors have had a significant role in the expansion of London and its neighbouring towns, and will continue to be important in influencing the nature of future urban, rural and industrial development. By giving consideration to geological information at an early stage in the planning of work that impinges on the ground in any way it may be possible to mitigate some of the problems commonly encountered. The key ground-related issues in the London district are discussed briefly below; many of them are related to specific geological units (Table 21). Key issues in south-west Essex were identified and discussed in detail by Moorlock and Smith (1991), and those in the Thames Gateway (a corridor extending astride the River Thames from London Docklands to Gravesend and Tilbury) by Ellison et al. (1998).

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Contents

WATER RESOURCES

Chalk is the principal aquifer of the London region. It is confined by the London Clay in much of the district and is in hydraulic continuity with the overlying sands of the Thanet Sand and Upnor formations, which together are commonly referred to as the 'Basal Sands'. The upper boundary of the aquifer is generally regarded as a clay layer with a thickness greater than about 3 m. In most places this clay lies within the Lambeth Group; it is coincident with the Lower Shelly Clay in much of central London, the Reading Formation in the west and north of the district, but probably the London Clay in the south-east of the district where the lower Palaeogene strata consist mainly of sand.

The Chalk aquifer is naturally recharged by rainfall at outcrop in the Chiltern Hills to the north and the North Downs to the south. The groundwater flows towards the centre of the London Basin. Prior to abstraction in the 19th century it discharged mainly at springs, many under artesian conditions, in Chalk valleys and along the Thames particularly between Erith and Gravesend (Figure 46).

Relatively minor aquifers in the district include the River Terrace Deposits, the confined Lower Greensand in the south-east and, locally, the Bagshot Formation.

The majority of the Chalk public supply sources in the Chalk aquifer are in the North Downs and the Darent and Lea valleys. Development is now taking place in the Greater London area to use the confined Chalk aquifer resource resulting from rising groundwater. Small quantities are abstracted from sources in the Lower Greensand from wells through the Chalk in the North Downs.

Development of groundwater resources in the London Basin

The growth of the City of London was constrained for many centuries by the availability of local water supplies, thus early expansion of the city was restricted to areas where river gravels are present. Until the 13th century water supplies for London were obtained from the Thames and its tributaries, and from springs and shallow wells in the river gravels. As the city expanded these resources became inadequate or polluted and further supplies were obtained via conduits, including the New River, from the Chiltern Hills. In the 18th century attempts were made to develop deeper groundwater beneath London. The first deep wells in the Chalk were constructed in the 1820s, although there was probably a reluctance to develop the confined aquifer because of difficulties in coping with the quicksands within the basal sands that were under artesian pressure (Barrow and Wills, 1913). By the 1890s, many of the early large diameter wells in the Chalk also had adits, some heading several hundreds of metres from the main shaft.

The rate of abstraction from the confined part of the aquifer peaked around 1940 and subsequently decreased, whereas that from the unconfined area continued to rise until the 1970s. Public water supply has dominated water use since the 1860s. The broad change in groundwater abstraction over the whole of the London Basin in the period 1820 to 1985 is shown in Figure 47.

The yields of wells and boreholes in the Chalk (Table 22) depend mainly on the transmissivity of the aquifer at the site, the type of construction and the thickness of aquifer penetrated. There is a general decrease in aquifer permeability from the Chalk outcrop towards the centre of the London Basin.

In the confined Chalk, groundwater is considered to flow in corridors of high permeability Chalk separated by blocks of low yield. Where Chalk is deeply confined, yield is commonly low. Yields from individual large-diameter wells at favourable valley sites at outcrop may exceed 9000 m3/day. Yields from pumping stations in the outcrop area, which may have several wells and may include adits, often exceed 14 000 m3/day. By contrast, in the confined aquifer, yields are usually considerably less, commonly of hundreds of m3/day. Some very high yielding sites (in the order of 7000 to 10 000 m3/day) in the confined aquifer are probably related to the high permeability corridors.

A measure of the specific capacity of boreholes in the Chalk (Monkhouse, 1995) has been estimated from the yield drawdown relationship of boreholes, normalised to 305 mm diameter and standardised per metre of saturated borehole length. The data indicate an area of low yield in central London, with standardised specific capacities of less than 0.1 m/day, which is surrounded by an area with values between 0.1 and 1.0 m/day. Areas of high yield, with standardised specific capacities exceeding 1.0 m/day, occur in the vicinity of the River Lea, the eastern part of the Thames valley and in the north-west of the region (Figure 48).

Hydrogeological characteristics of the Chalk

The Chalk is hydraulically a highly complex aquifer. Its matrix has a high porosity, commonly of the order of 35 per cent (Bloomfield et al., 1996), but the pores are extremely small and thus the hydraulic conductivity of the Chalk is very low, with values averaging around 10-3 m/day (Allen et al., 1997). The ability of the Chalk to act as an aquifer is therefore due almost entirely to its fractured nature.

Hydraulically significant fractures in the Chalk do not extend through its full thickness, but are concentrated in the upper few tens of metres. In the unconfined Chalk they are most prevalent in the zone of oscillation of the water table where many are enlarged by dissolution. Important water-bearing fractures have been shown to extend to depths of the order of 50 m below the water table. In the confined Chalk and 'Basal Sands' aquifer, the majority of inflows to boreholes, shown by geophysical flow logging, typically occur within 20 to 30 m of the upper surface of the Chalk.

The main controls on the transmissivity of the unconfined Chalk are depth and topography. The highest values, in excess of 1000 m2/d (Allen et al., 1997), are in valleys, for example the Darent and Cray valleys in the south-east of the district (Figure 49). Transmissivity is significantly lower in interfluve areas, where values in the order of a few tens of m2/d are likely. The main reason for the contrast is that in valleys the Chalk is likely to be relatively highly fractured and the fractures enhanced by dissolution (Younger, 1989).

Swallow holes and other karstic features in the Chalk strongly influence the transmissivity. For example, a swallow hole at Addington, Croydon [36 64] is connected to a complex shallow fracture system in which tracers moved a rapid 3 km/day (Richards and Brincker, 1908). The development of karstic features within the Chalk is related to the diversion and concentration of groundwater flow by relatively impermeable beds such as tabular flints, marl seams and hard, nodular chalk. These occur in particular parts of the Chalk sequence (see Chapter 3, Upper Chalk) and thus areas of relatively karstic Chalk can be predicted. In the confined Chalk, transmissivity is generally highest in areas of greatest fracturing, thinnest overburden and largest groundwater flux. For example, it is low north-east of the River Lea, where the overburden is thick, but enhanced along the Colne and Lea valleys in the north and the Mole and Wandle in the south of the district. Groundwater associated with these valleys tends to be young, indicating they are zones of preferential flow. The zone of moderate transmissivity in central London (Figure 49) may be due to relatively enlarged Chalk fractures in areas of former springs. It may also relate to north-west-trending faults and fractures (see Chapter 7). In south London, zones of high transmissivity correspond approximately to the location of faults, notably the Greenwich Fault (see Figure 44), whereas permeablity across such faults may be low (Allen et al., 1997).

Water quality in the Chalk and 'Basal Sands' aquifer

The general distribution of groundwater types in Chalk and 'Basal Sands' aquifer in the London Basin is shown in Figure 50. Chalk outcrops in the north and south of the district, and in the Lea and Wandle valleys, are characterised by hard, calcium bicarbonate water. In the axis of the London Basin soft, sodium-rich groundwater is present. Sodium chloride water occurs along the lower reaches of the River Thames because of saline intrusion (Water Resources Board, 1972).

Groundwater management and protection issues

In central London the original natural groundwater level was 7.5 m above OD. This was lowered to around 88 m below OD by the mid-1960s, due to pumping from boreholes, illustrated by the hydrograph of a well in Trafalgar Square (Figure 51); the top of the Chalk succession is dewatered over several square kilometres (Lucas and Robinson, 1995).

The fall in groundwater levels in the confined aquifer caused a reduction in spring flows and some river flows, and induced the intrusion of saline water from the Thames into the Chalk downstream of the Isle of Dogs. Reduction in groundwater abstraction, since around 1965, has resulted in recovery of the groundwater level and a reduction in the cone of depression; rates of water level rise approached 3 m/year in places in the 1990s (Figure 51). More recently, rates of rise in central London have decreased to around 0.5 m/year (Environment Agency, 2001), due to a combination of natural causes and a strategy to manage the water levels†.

Artificial recharge

The lowered groundwater level resulting from pumping in the London Basin has provided the opportunity to use part of the dewatered Chalk and 'Basal Sands' aquifer in north London for artificial recharge. This technique involves using the unsaturated part of the aquifer as a reservoir into which water is emplaced during times of surplus, and extracted when required, mainly in times of drought. In the case of the Chalk and 'Basal Sands' aquifer, the high storage coefficient sands are able to store water while the high transmissivity of the underlying Chalk allows relatively easy flow of water into and out of the aquifer.

The principle has been applied in the Enfield, Haringey and Lea valley area (O'Shea, 1994). It works by pumping treated water, during the winter or other periods when there is excess, into wells that penetrate the aquifer. This water is stored in the Chalk and 'Basal Sands'. When required, for example during times of drought, the stored water is pumped from the same wells either into reservoirs in the Lea valley or into a water transfer system which includes the New River, an engineered aqueduct through Enfield [e.g. 340 980] and Hornsey [e.g. 312 892]. The scheme has a drought yield of about 150 000 m3/d from 35 wells. A similar one is being investigated in south London where there is little or no unsaturated storage available in the Chalk or 'Basal Sands' aquifer. However, large abstractions in the Wandle valley [257 740] have increased the confined storage available for artificial recharge.

There is an apparent contradiction in artificially recharging an aquifer that elsewhere is causing problems as a result of rising water levels. However, there is no evidence that the artificial recharge in north London influences the rising groundwater trend in central London. Theoretical studies, supported by monitoring since 1995, indicated that the temporary cones of impression caused by the injected water would be removed by abstraction before the water moves down the hydraulic gradient to affect the central London water levels.

Low flow alleviation

Until the late 1990s, the River Darent frequently dried in its middle reaches in years when recharge and groundwater levels were significantly lower than normal. This resulted in damage to river ecology as well as loss of amenity. Under average conditions, throughout the greater part of its length, the river should gain flow from groundwater. In fact river flow decreases north of Shoreham [52 62]. The main cause of this is leakage of river water through the river-bed and into the underlying Chalk aquifer as a result of the lowering of the water table caused by abstraction from nearby groundwater sources. The impact on the river becomes more marked in times of naturally occurring ‘dry’ winters as experienced in 1992/93, when there was no flow at Horton Kirby [56 68].

In order to resolve the low flow problem, the Environment Agency and the water company concerned have agreed a phased programme to reduce abstraction from the Chalk in the middle part of the River Darent, with river augmentation boreholes being constructed and new Chalk groundwater resources developed to the north-east, outside the immediate catchment of the Darent.

GROUND CONDITIONS

Engineering implications of changes in groundwater levels

The recovery of groundwater levels in London has several implications for engineering (CIRIA, 1989). Basements or tunnels above the water table and not sealed against the ingress of water are liable to flooding. Sealed structures submerged by rising water could become buoyant and liable to uplift pressures detrimental to stability. Structures originally below the water table may not be sufficiently watertight to contend with increased hydrostatic head, in which case remedial sealing or continuous pumping would be required.

Some tunnels are currently suffering from increased seepage, and chemical attack. One example is on the London Underground Northern Line, where highly acidic waters caused deterioration of the tunnel linings south of Old Street Station [328 826]. Investigations suggested that the source of the acid was oxidised pyrite in sands of the Harwich Formation and the Lambeth Group. These sands were originally saturated, but subsequently dewatered as the water table lowered. The pyrite was oxidised by air from the railway tunnels, in particular by the piston effect of passing trains and by changes in barometric pressure. Water seeping from the overlying London Clay into the newly created unsaturated zone resulted in the production of highly acidic, aggressive groundwater (Robins et al., 1997). This situation could be exacerbated as the water table rises (Rainey and Rosenbaum, 1989), but is being minimised by the GARDIT strategy.

During conditions of falling ground water level, the resultant underdrainage and consolidation of strata resulted in an estimated 300 mm of subsidence in central London (Water Resources Board, 1972). It also increased the bearing strength of the London Clay and clays in the Lambeth Group. As a result of rising groundwater, increase in pore water pressure and the swelling of clay, particularly the montmorillonite-rich London Clay, may result in a loss of shear strength, and hence bearing capacity. Chisholm (1984) for example showed that the bearing capacity of deep foundations and piles would experience a drop of between 25 and 50 per cent if the water level in the Thanet Sand Formation below central London rose to ground level. In addition there would be uplift pressures under basement slabs and increased earth pressure on the side walls causing differential movement and significant damage to buildings (CIRIA, 1989). The risk of these hazards having an impact is significantly reduced by implementation of the GARDIT strategy.

Deep drift-filled hollows

Deep drift-filled hollows (see Figure 35)encountered during excavation may require dewatering. It may also be necessary to control running sand during excavation and construction. The heterogeneous, non-cohesive infill and the potentially slumped and sheared sides of the hollow may cause instability problems in excavations within, or cutting across, the margins of a drift-filled hollow.

The unexpected penetration of a deep, steep-sided hollow filled with water-bearing gravel presents a serious hazard to shallow tunnelling operations in the London Clay due to potential flooding of the workings, the need to stabilise the drive and to seal the finished tunnel lining. The problems caused by such features during the construction of the Brixton extension of the Victoria Line required the use of timber support, grouting and compressed air to enable the works to proceed through the water-bearing gravel infill (Megraw, 1970).

Chalk dissolution and weathering

Weathering of the Chalk and the development of dissolution features are closely related to lithology, fracture density and water table fluctuations. The Chalk exhibits a wide variety of surface karst features. The most common of these are dissolution ‘pipes’. They are deep, narrow features extending down from the surface, possibly with no surface expression. Most of them are cylindrical, but they may be cone-shaped, pinnacled, or dish shaped (Farrant, 2001), and range from 1 to 20 m in diameter. Pipes may penetrate several tens of metres below rock-head and are usually infilled with Clay-with-flints, sand or clay derived from the overlying superficial or Palaeogene deposits (Figure 52). The larger dissolution features occur close to the outcrop of the base of the Thanet Sand, particularly where there is a large catchment area of the relatively impermeable Lambeth Group and London Clay. This leads to a relatively large volumes of runoff being directed down valleys cut into the permeable Thanet Sand and Chalk. The resultant development of pipes and swallow holes in the Chalk beneath the valley floor locally leads to collapse of Thanet Sand, and occasionally of higher strata. Numerous examples of sinkholes are known around Erith [51 78] and Crayford [51 75]. There are also many instances of them at or close to the boundary between the Chalk and Paleogene deposits, for example near Well Hill [495 644]. Large dissolution cavities filled with Thanet Sand and soliflucted superficial deposits are common in north Kent, particularly between Northfleet Green [627 711] and Cobham [670 685]. Dissolution of the Chalk occurs also in the floor of valleys, where joints are relatively common, and on the dissected dip slope of the North Downs in the south-east of the district. Where Chalk crops out on valley sides there is generally minor surface dissolution (Figure 52). Sinkholes can be reactivated artificially by concentrations of water resulting from leaking water pipes, drains or soak-aways, and in such cases collapse of the overlying ground into the cavity may take place.

Another form of karst is associated with flint and marl seams that are sufficiently continuous to act as local aquicludes. For example, the Belle Tout and Shoreham Marls and the Seven Sisters Flint (see Figure 7) in the Upper Chalk exposed in the Swanscombe quarries [580 735; 59 73] display karstic features along their top surfaces formed above the water table.

At depth, below Palaeogene strata under London, joints in the Chalk are tight and coated with a black (ferrous iron oxide) powdery residue, but with little evidence of dissolution. In comparison, joints in the saturated Chalk directly below Thames gravels and alluvium are coated with red-brown, ferric iron oxide, but with little evidence of major dissolution even though there is water flow along discontinuities.

The Chalk weathering profile is the legacy of freeze-thaw action under periglacial conditions during the last ice age. Chalk at the surface is usually highly fractured, with a network of curviplanar discontinuities, typical of frost shattering, which extend to depths of 30 m. For example boreholes at West Thurrock [581 791] encountered 15 to 20 m of intensely fractured weak Chalk, and at sites between Erith and Crayford ‘rubbly chalk’ is locally recemented to form a breccia (Dewey et al., 1924).

The systematic description of Chalk (Spink and Norbury, 1990) is based on the Mundford scheme (Ward et al., 1968). On the basis of fracture spacing and dilation, six weathering grades, I–VI, are recognised. Grade VI, the most highly weathered, occurs at the surface and directly below superficial deposits. It is similar to a cohesive soil, consisting of coarse to fine gravel grade chalk fragments in a silt grade matrix. Grades I to V encompass a gradation from ‘structured chalk’, in which the original structure of joints, fractures and bedding can be identified, to ‘structureless chalk’ in which most of the primary structure is destroyed and lumps of soft chalk lie in a subordinate, fine putty, chalk matrix.

Chalk is sensitive to frost action. Soft chalk, such as the weathered Upper Chalk at outcrop in north Kent, starts to transform to a chalk putty after four to ten freeze thaw cycles. Harder chalk, such as the Lewes Chalk, is more resistant and may only suffer frost cracking (Bell et al., 1997). Lewis and Croney (1965) described contemporary frost heave caused by the formation of ice lenses up to 25 mm thick along chalk bedding planes. Higginbottom (1966) suggested this mechanism can lead to a total volume increase of 20 to 30 per cent. Freeze/thaw action may be significant also in the long-term stability of cut Chalk faces in engineered cuttings.

Engineering characteristics of the Chalk

Moisture content of chalk (Table 23a) is generally greater than 25 per cent and dry density values of the Upper Chalk indicate it is soft to extremely soft (Higginbottom, 1966; Lewis and Croney, 1966). Unconfined compressive strength data of saturated samples of Upper Chalk from Kent fall in the weak rock range (1.25–5 MPa). Dry samples are stronger, in the moderately weak rocks range (5–12.5 MPa). The Upper Chalk of the London district is appreciably weaker by a factor of five or six than chalk from Norfolk and Yorkshire (Bell, 1977).

The load bearing capacity of both bored and driven piles in chalk is impaired due to skin friction being reduced by a coating of remoulded chalk paste left plastered on the hole during drilling. Similar chalk paste is formed in the process of pile driving. A comprehensive review of piling in chalk was carried out by Hobbs and Healey (1979) and updated by Lord (1990).

Artesian pressure in Chalk can lead to problems in construction. For example, during the construction of the Thames Barrier (Horner, 1984) it caused uplift of strata, and the excavation of concrete slabs cast to seal the formation at the bottom of a coffer dam. Extensive dewatering carried out from boreholes mitigated artesian conditions encountered during tunnelling in chalk for the Thames Cable Tunnel from Gravesend to Tilbury. Two major fissures were encountered during the drive that required temporary bulkheads to be built to stem the flow of water so that grouting could be achieved in static conditions (Haswell, 1969). In addition, recharge wells were installed to avoid subsidence damage to nearby property.

The efficiency of tunnel boring machines operating in Chalk is reduced by flint bands, and by the build-up of putty chalk. Haul roads in major excavations suffer from poor trafficability in wet weather where chalk becomes over compacted crushed and remoulded by the traffic. In particularly wet conditions it becomes a slurry.

Engineering characteristics of the Thanet Sand Formation

The Thanet Sand Formation is a non-cohesive granular deposit. It has the physical characteristic of a weak rock, but can be disaggregated by light finger pressure. The apparent cohesion is due to mechanical interlocking of subangular grains; this is characterisatic of a ‘locked sand’ (Barton and Palmer, 1989). Geotechnical Properties are summarised in Table 23b (see also Howland, 1991).

Weathered and/or cryoturbated Thanet Sand may have a low bearing capacity and suffer high settlement on loading. In comparison, undisturbed Thanet Sand has a high bearing capacity with no appreciable change with depth due to the dense nature of the deposit. The sinking of bored piles requires the use of bentonite slurry to avoid the hole collapsing below the water table. In the Canary

Wharf Development [38 80], base grouting of bored piles was used (Troughton, 1992).

At surface outcrops, the Thanet Sand is easily dug using normal earth-moving equipment. Excavations above the water table stand at a high angle in the short term, but running sand conditions occur below the water table.

In tunnelling, the Thanet Sand is considered abrasive, due to the angularity of its grains, and causes high rates of wear on machinery. (Clarke and Mackenzie, 1994). Large unworn flints ('bullhead flints') in the basal bed can cause problems on the tunnel face. Sudden inflows of running sand can occur in excavations and tunnelling below the water table. For example pore water at a pressure of 3 bars caused water to flood a tunnel being driven for the London drinking water Ring Main, and filled it with 100 m3 of sand (Clarke and Mackenzie, 1994). Preventative measures against such hazards include balancing the air pressure in the workings with the water pressure of the groundwater, dewatering, ground freezing, grouting in advance of the face, the use of a full-face slurry-tunnelling machine or earth-pressure-balance tunnel-boring machine (Clarke and Mackenzie, 1994; Oliver, 1996).

Engineering characteristics of the Lambeth Group

The horizontal and vertical variability of the Lambeth Group is a source of continuing challenges for construction; tunnelling in these deposits, in particular, is a source of unforeseen expense (Table 23c). Generally, no tunnelling method is suited to a rapidly changing composition of the face, but problems can be minimised if techniques are determined in advance, using a ground model. The basis for such a model is recovery of good undisturbed ground investigation borehole samples, as described by Mair (1993) and Linney and Page (1996) for major infrastructure projects in London.

In engineering terms the clays in the Lambeth Group have broadly similar properties to London Clay (see p.97). The main exception is where they contain appreciable amounts of calcareous shell debris in the Woolwich Formation Upper and Lower Shelly Clay units. The sands are similar to the Thanet Sand but are generally coarser grained, more poorly sorted and not 'locked'. Summary geotechnical properties are given in Table 23c.

Lithologies in the Lambeth Group that can cause problems in excavation are flint pebble beds (in the Upnor Formation), calcareous nodules (Reading Formation) and other locally cemented beds (Woolwich and Upnor formations), weak to strong limestone beds (Woolwich Formation; Upper Shelly Clay), irregular-shaped sand bodies (Woolwich Formation; Laminated beds) and swelling clays (Reading Formation). Excavations are likely to encounter water-bearing sands and therefore support is required. Seepage from perched water tables on the side slopes of cuttings may cause slope instability, and slopes in sands need to be protected from erosion caused by surface run off.

The difficulty of tunnelling in the Lambeth Group was evident during construction of Sir Marc Isambard Brunel's tunnel beneath the Thames from Wapping to Rotherhithe. It took 18 years to complete, from 1825 to 1843, and was flooded on five occasions (Skempton and Chrimes, 1994). The prospect of similar problems was largely responsible for the greater part of the London Underground railway system being constructed north of the River Thames, in the London Clay, rather than south of the river where the Lambeth Group is at or close to the surface.

Several designs of tunnel-boring machines were used to good effect in the Lambeth Group during the installation of a new sewerage system in London's Docklands (Ferguson et al., 1991). In predominately clay strata, where there is minimal risk of water ingress, open-face tunnelling was used. In coarser material, a closed-face Earth Pressure Balance Machine (EPBM) or a slurry shield was effective. EPBM tunnelling in mixed lithologies, and progress with a slurry shield machine may be slow due to clogging of pipes and intakes by the clay component of a mixed face. Tunnelling through the Lambeth Group, which is composed of sand, silt and swelling clay with gravel lenses in the Bermondsey section of the Jubilee Line Extension, led to a problem with the removal of material through the discharge auger; this was solved with the addition of a foaming agent (Oliver, 1996b).

Control of groundwater inflow into Lambeth Group excavations has been achieved by ground freezing, removing water by well point dewatering, excluding water by grouting permeable horizons in advance of the face and by balancing water pressure by working in compressed air.

Engineering characteristics of the London Clay Formation

From an engineering point of view the London Clay is arguably the most important geological formation in the United Kingdom in terms of the number and value of structures founded on it (Table 23d).

The geotechnical properties of the London Clay Formation are fairly consistent. In the east of the district, the top 30 m of the formation, including the Claygate Member, is less sandy and more plastic than in the west (Burnett and Fookes, 1974). In comparison, vertical lithology changes in the sequence (see pp.45–47) are marginally more significant.

Weathered London Clay is brown in colour, and soft to stiff; unweathered London Clay, is grey in colour, and stiff to very stiff, becoming hard with depth (see Figure 25). Chandler (2000) examined the changes in geotechnical properties as a result of weathering. Permeability is low, in general, but silt and sand beds and fissures have higher values. Moisture content decreases and density increases with depth. Where the clay is desiccated at the surface it has a higher density and lower moisture content than the material immediately below it.

The bottom of excavations in London Clay may suffer heave due to stress relief and swelling on wetting. Railway and road cuttings may be similarly affected over a period of 30 years or more.

London Clay is well suited to tunnelling using a variety of techniques (Attewell and Farmer, 1974; Dick and Jaques, 1994), most of which have a face shield for support. The amount of subsidence caused by different tunnelling methods can be predicted (Heath and West, 1996), and several grouting techniques are used in its mitigation (Kimmance et al., 1995). Compensation grouting from fan-shaped spreads was used in the vicinity of the Jubilee Line Extension to protect buildings in Westminster, for example The Treasury and Big Ben (Winney, 1996).

Engineering characteristics of 'brickearth'

'Brickearth' is typically firm to stiff and of low to medium plasticity. In places, it may be of low density, with an open structure that leads to instability. This can result in sudden collapse when a critical load is exceeded or the material is wetted under load.

The potential for instability is removed when the primary structure is destroyed by reworking and in this circumstance 'brickearth' can be used in earthworks. There is little published information on the engineering properties and behaviour of the 'brickearth' of the London area, although similar, generally thicker deposits have been studied in south-east Essex (Northmore et al., 1996) and Kent (Derbyshire and Mellors, 1988). Engineering characteristics of Alluvium The deposits mapped as alluvium and estuarine alluvium are normally consolidated, generally very soft to soft, with high compressibility exacerbated by peat beds (Marsland, 1986). A firm to stiff, desiccated surface zone may be present. The deposits are characterised by low bearing capacity and poor foundation conditions due to high and/or uneven settlement. Running sand conditions may be encountered in excavations below the water table, and excavations may need immediate support.

Chalk mining

Man-made cavities in the Chalk have been made during flint mining and chalk extraction, probably from pre-Roman times until the 19th century. The mines are typically narrow vertical shafts 10 to 20 m deep, known as dene holes that in some areas may be only 20 m apart. At the base of the shaft there may be a bell-shaped excavation or a number of short galleries. Edmonds et al. (1987) and Bell et al. (1992) described the methods of working. Mines are known in the Chalk at Pinner [114 906], Chiselhurst [4275 7015], at several locations near Plumstead [e.g. 472 784; 464 774], and Blackheath [383 767]. As there are few mine plans, there may be other, undocumented mines in these and other areas, for example at Blackheath Common [393 765] where there was discussion about the causes of sudden ground collapse (Laughton, 1881). Mined cavities are usually stable, but the material with which they have been backfilled may suddenly subside and collapse due to the effects of natural drainage, leaking services or rainwater soakaways. Such instability may also occur due to slow deterioration of gallery roofs. In this case, the resultant collapse may lead to upward migration of the void and consequently sudden subsidence of the ground surface.

Slope stability

The natural maximum angle of repose of chalk is around 37° (Toms, 1966). The British Standard Code of practice for earthworks (BS 6031, 1981) recommends angles of repose for chalk embankments of between 33º and 37º. Williams (1990) suggested that slopes less than 56º will not undergo significant degradation, but a slope of 45º or less is required for the establishment of a vegetation cover. Cut slopes up to 76º can be maintained if some spalling is acceptable.

Landslides on London Clay slopes are well known, and have been the subject of much research (for example Skempton, 1964; Hutchinson and Gostelow, 1976). The stable angle for natural slopes in London Clay was determined as 10º by Skempton and DeLory (1957), whereas Hutchinson (1967) concluded that an angle of 8º was the ultimate angle of stability. The Claygate Member, at the top of the London Clay, is more susceptible to slope instability than the bulk of the London Clay. It has high plasticity and high moisture content on account of water-bearing sand layers. Where the Claygate Member is overlain by water-bearing sand in the Bagshot Formation a spring line may develop, which raises pore water pressures and saturates the material below it. Slopes of 8º or greater on Claygate Member are potentially unstable.

Many London Clay slopes greater than 3° are covered with a veneer of head, which may not be shown on the geological maps. Culshaw and Crummy (1991) suggested that these too should be considered as potentially unstable. The head is composed of redeposited London Clay, including the Claygate Member; it is derived by downslope solifluction and soil creep and may contain relict shear surfaces. The shear strength is likely to be at, or close to, its residual value. Reactivation of the shear surfaces may occur if the slopes are undercut, loaded, saturated or the water table rises.

Low permeability clay layers within the Bagshot Formation may create perched water tables within it, which may impair slope stability. Unprotected cut slopes or embankment slopes in uncemented sands, such as the Bagshot, Harwich, Upnor and Thanet Sand formations, may suffer rapid erosion from surface run-off and require the slope to be drained, protected by vegetation or the water diverted.

Clay swell-shrink

Large areas of the district where London Clay is at or close to the surface, particularly north-west and south-west London, are affected by the problem of ground movement caused by alternate swelling and shrinking of the clay. This is caused by the smectite content of the clay, which expands when wet and contracts on drying out. Swell-shrink occurs, but to a lesser extent, on outcrops of till and Lambeth Group

Annual moisture changes in soils developed on the London Clay can cause the ground surface of a grass-covered area to rise and fall over the year by 50 mm (Building Research Establishment, 1996). However, vegetation has a significant role in the desiccation of the soil and this figure can rise to 100 mm near to trees. Depending on the species, trees can reduce soil moisture to a depth of 5 m (McEntee, 1984). Unrecoverable heave of 12 mm was measured by Driscoll (1984) over a three year period and 80 mm was recorded on rehydration of the soil after the removal of trees (Building Research Establishment, 1996) a process that may continue for more than 20 years before moisture equilibrium with the surrounding clay is re-established (Cheney 1988). Thus, structures may be damaged by subsidence due to progressive desiccation of the soil over a series of drought years especially if the effect is enhanced by trees, or they may be damaged by heave when soils swell on re-hydration after the removal of trees.

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- Not logged in
- Talk
- Contributions
- Log in
- Request account

Namespaces

- Page
- Discussion

☐

Variants

Views

- Read
- Edit
- View history
- PDF Export

☐

More

Search

Search Go

Navigation

- Main page
- Recent changes
- Random page
- Help about MediaWiki

Tools

- What links here
- Related changes
- Special pages
- Permanent link
- Page information
- Cite this page
- Browse properties