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Urban development: Decisions making processes in the planning of sub-structure construction

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ABSTRACT: All building and civil engineering projects needing basement and sub-structures require geotechnical engineers to work closely with a project team from the project conception through to completion in order to identify and manage the risks that the ground and surroundings present. The appreciation of these risks requires an understanding of the way in which cities have and are evolving and an appreciation of the institutional framework within which we operate. The paper describes how such projects evolve and draws a distinction between the smaller scale 'domestic' basement schemes and 'commercial' schemes both of which present new challenges to our skill and ingenuity.

1 INTRODUCTION

The main object of this paper is to try to put the sort of projects, observations and analytical approaches that form the subject of this technical conference into the context of the general development of building projects within the city environment. Sub-structures are a critical element of any project and are often the most controversial. They are the part that involves the greatest risk in terms of time and cost. The paper aims to highlight the main steps that have to be taken during the various stages of any project in order to ensure that these risks are addressed within the institutional framework within which we all operate.

The secondary objective is to highlight the often neglected, but extremely demanding subject of the development of domestic basements and to look at the challenges that these present and how they differ from the large basements and substructures that mostly form the subject of technical discussions in this field.

As geotechnical engineers many of us work on projects in urban areas where the construction of new buildings has an impact on the surroundings, be it the inconvenience caused by the process of construction or the possibility of physical damage to adjacent structures or services. The population of cities has increased as a result of general expansion and the shift from the rural areas, but constraints are imposed on expanding the city limits, urban development has had to use the available space more efficiently. This doesn't just apply to buildings. It also applies to transport and infrastructure. As our cities get more mature, we have therefore to make better use of what we have got already and work within the constraints that this imposes. On the positive side we want to conserve what is good from the past, but we have to work round what the past has left us, for example, obstructions in the ground. Increasingly, the legislative framework within which we work has an enormous impact on the way that projects develop from their initial conception to final completion. This legislation is designed to protect our heritage, our environment and individuals. It is not designed to stifle development since a city without development cannot survive long term, it also provides the right to build things, provided that such development does not cause damage to the surroundings, in terms of visual impact, change to the environment and physical effects.

The history of construction in any particularly city has an enormous impact on the way we build now. This history often has wide influences: take London as an example. This is a city that has been occupied for more than two thousand years by a series of invaders, each bringing their own cultural influences and in the oldest parts of the city the current street levels are several meters above the original ground levels. In these parts all developments now have to consider the impact of any development on the archaeology, whereas they didn't 40 years ago. On a site that is suspected to be of archaeological interest, this can have a major and often uncertain impact on the potential development program because of the requirement to investigate prior to development and the need to minimize the impact of the development on what is found in the ground. A recent example of this is the investigation of the Temple of Mithras at the site of the new Bloomberg Headquarters which is currently under development. This has been described as the 'Pompeii of the North' and the archaeological dig has shifted some 3500 tones of soil to reveal the original building, an old stream bed running along side it and unearth an enormous number of artefacts dating back to the first century AD. The temple structure has been removed and it is planned to reconstruct it within the new building.

Another example in London is the Roman amphitheatre found under the Guildhall in London, which has been left in place within a 'tray' constructed to support it within a deep basement structure. Geotechnical engineers and structural engineers played a major part in both the investigations themselves and developing the means of preserving what has been found.

The commercial centre of London is largely within the old City area, but has expanded to new areas such as the Docklands area as the city has matured. The essential character of some of these old industrial areas has been retained in some of the more prominent areas. For example, along the river frontage to the Thames by refurbishing the existing buildings, many of which are on timber piles. Away from the river, the commercial buildings (on higher ground) are either supported on shallow foundations or piles, depending on the ground conditions and the size of the buildings. Concrete piles have been in use for around the last 90 years, but their use proliferated in the 1960's when buildings began to grow taller and the equipment to construct large diameter piles was imported from the USA and developed specifically for use in London conditions. Large basements for commercial buildings were first being constructed in the 1920's and 1930's for shops (e.g. Selfridges), underground railways, and banks, but these were exceptional. Basement construction proliferated in the 1960's and 1970's, accelerating when such techniques as diaphragm walling were imported (in the case of diaphragm walls, from Italy).

There are very few sites in London where there has not been development in the past and one of the big difficulties, particularly with commercial buildings, is that the buildings themselves have a limited lifespan, not in terms of the materials but in terms of their functionality and the need for them to provide a good letting return. Increasingly, the fashionable London shopping streets are being rebuilt behind the old facades to provide modern office space. What is perceived as acceptable for a high specification building attracting high rents changes over time. The general life span of such a building is around 25 years. Modern offices are often either newly built on the site of an existing building, or, where the building is of architectural merit, rebuilt internally often on a completely different floor plan, leaving a 'retained façade' to which the internal structure is matched. One of the challenges of these buildings is working within or around the old substructure and foundations of one or more former buildings.

There are few remaining very old buildings in the City as they were largely destroyed during the Great Fire of 1666. But away from the City and commercial areas, London is a sprawl of housing ranging largely in age from the mid 19th Century when there was a major expansion of housing stock and the big city estates were built, to the modern. There are enclaves of older housing in the areas where old villages (e.g., Hampstead) have merged into the London sprawl. These older areas have been designated 'Conservation' areas where tighter restrictions are imposed on development in order to ensure that the essential nature of the environment is preserved. Because of the limited stock of housing, prices are high, especially in these Conservation areas or nearby and the cost of moving to a larger house extremely high. Expansion of existing houses has become the cheaper option, but the constraints imposed by the Local Authorities and the National body responsible for preserving buildings mean that expansion underground is the only option. Many houses in the older estates already have shallow basements as a result of the innovative technique adopted of building up the surrounding roadways with the associated services (water and sewerage) using the excavated material from the basement. This adds to the complexity of extending downwards. London has become a place of 'iceberg homes' where there is sometimes more building below ground than above with basements expanding into the gardens outside the houses. Basements are constructed in very confined areas using techniques that would normally be used for large scale commercial basements. These types of developments are technically challenging and demand a high standard of construction if they are to be done safely. They are also often deeply unpopular because of the disruption that they create to the surroundings for extended periods of time, and the regulatory authorities have a hard job keeping everyone happy. Pressure groups have been pushing to pass national laws which restrict the scale of any such development.

The history of development of the infrastructure reflects the life of the city as it has expanded. The technology to make provision for our needs for transport, power and sanitation has changed with time. Much of this infrastructure is under the ground in order to enable unimpeded movement at street level. The step change that took place in the 18th Century as a result of the advancement of engineering processes and the advent of the railways has both shaped the layout of the modern City and left a legacy of aging infrastructure which requires maintenance and has become inadequate. Although the first underground railway in the world was built in London, local transportation was provided at street level by an extensive tramway system which, although no longer evident because of the advent of the car, has still left a legacy of old tunnels. Where it is still in use, to preserve the old infrastructure and not to adversely affect it when undertaking further development, has become increasingly difficult. The expansion of this infrastructure has increased as the urban areas have expanded and changed from industrial use to residential areas, particularly in the case of transportation. Not only do we demand rapid movement into and across the City, but we also want to extend existing networks to open up new areas both within the City and outside. Such expansion, more often than not, requires going deeper and deeper into the ground in order to go below all the existing infrastructure, creating deep tunnels through complex ground. Access to and from these tunnels requires the construction of deep shafts and station complexes.

2 DOMESTIC DEVELOPMENTS

London is typical of any city which has evolved organically and its buildings reflect the social changes that have taken place over the centuries and which are taking place even more rapidly today. Our ability to build things is almost unlimited, but, whether we should build things is a different matter. This is an issue which goes to the root of our professional lives as we have to operate within a social framework which is often peculiar to our own local environment. However, we all still have to go through broadly the same decision making processes when approaching a new project. Although, in some ways, geotechnical engineers are removed from these issues because we are not actually at the 'front end' of the decision making process, some of the greatest risks to most of the projects that we get involved in are in the underground development and other professionals are relying on the advice that we give in both the identification of risk and its quantification. This applies to the more obvious cases of large commercial developments and infrastructure projects (which are generally the subject of conference papers, such as this) but it may apply even more to the increasing number of 'domestic' developments where it is perceived that work can be safely carried out without the same expertise (either in terms of design or construction) as applied to the large structures. Such a perception is misconceived. Many domestic developments are more complex than their commercial counterparts not least because the basements are often constructed with the existing building in place. The design of 'domestic' basements requires the same skill set as required for any other substructure development and employs the same range of geotechnical processes. It also requires an attention to detail in construction, which often surpasses that required for larger projects. It is also now common practice to undertake detailed monitoring of structural movement in order to ensure that something unexpected is not happening. The reason for the attention to detail is the impact that movement resulting from construction may have an immediate and obvious effect on relatively weak structures in very close proximity and this causes stress to the individuals concerned.

An example of one of the more complex 'domestic' basement schemes is given in Figure 1 which illustrates a development in a street in the wealthy Mayfair area of London. The original main building is around 200 years old with 4 storeys above ground level at the front and a more recent 2 storey building at the rear, with a courtyard between. The site is around 10 meters wide. The main building was to be retained and a two level basement was to be constructed below the level of the existing semi-basement over the entire site. The ground is made ground and alluvial deposits over gravels and London Clay. The original scheme was to install a secant bored pile wall (hard/soft) all around the inside of the peripheral walls, but this was not favored by the owner, as is so often the case, because of the amount of basement space that such a wall occupies once all

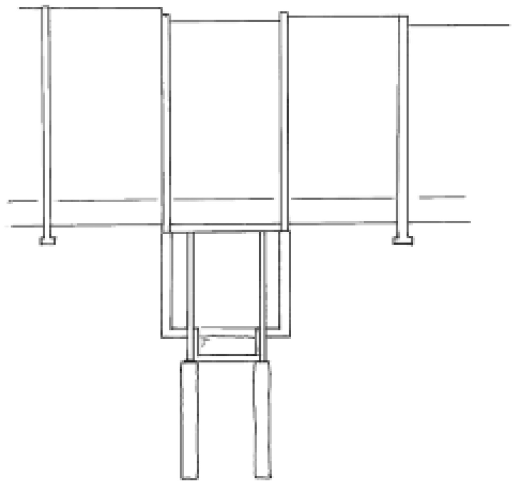

Figure 1. Section through terrace of buildings showing basement.

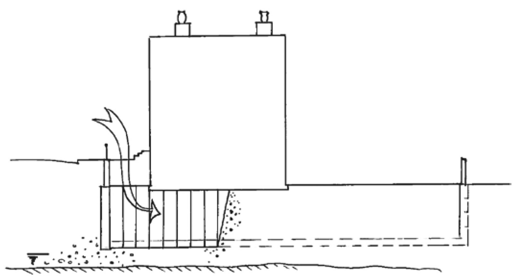

Figure 2. Section across terrace showing means of constructing basement under house.

finishes and internal walls have been completed. The favored solution was to underpin all but the rear boundary walls using reinforced concrete underpins which would both transfer the vertical loads downwards and retain the ground. However, it was considered a risk in these ground conditions to rely on underpins alone. To reduce the risk of settlement the existing building and the boundary walls were tied into a ground beam system and supported on two lines of hand-dug caissons constructed from the existing basement. These were terminated at the level of the underside of the new basement and the columns to support the ground beams were placed and jacked to take up an initial load. The underpins were then constructed from a central excavated area in two 'lifts', digging in from the central area to form each pin. Flat-jacks were installed to preload the underpins during the dry-packing process. The maximum settlement measured during this work was around 10 mm. This caused some minor cracking in one of the adjacent basements. It is worth noting that the basements of both the adjacent buildings were extended downwards at a later date.

Another unusual example at a smaller scale is illustrated in Figure 2. The property in question was towards the end of a terrace of three storey buildings, each with an existing semi-basement. The owner wanted to construct a new basement under the house and the garden, but had previously refurbished the property and did not want to work from within the existing house. The scheme that was developed involved initially constructing the basement within the light well area at the front of the house, including underpins to the front wall of the house itself. The side walls of the house were then underpinned working from a central area accessed through an opening in the underpins to the front wall, progressively extending the walls and central excavation towards the rear of the house, supporting the existing basement floor on steel joists propped off the ground at excavation level. This process was continued into the rear garden.

This paper attempts to deal with the broader range of sub-structure developments, and although drawing a distinction between 'domestic' and 'commercial' construction there are many commonalities when it comes to the decision making processes, particularly at the earlier stages. Some of the differences occur because of scale, but this is not always the case. 'Domestic' basements covering a plot of 40 meters × 70 meters with depths of the order of 20 meters have been planned but they are more commonly on a much more modest scale.

The issues that characterize 'domestic' basements are:

– The new basement is to be constructed under the existing garden and/or house.
– The existing property (and adjoining properties) are generally masonry (often brick) and may be poor. Walls often have many openings for windows and doors and are therefore weak. In older properties damage may already have occurred and been repaired. They are thus generally vulnerably to effects of movement at both foundation level and due to changes in horizontal support.
– Existing foundations may be of poor quality on poor ground.
– The existing property cannot (generally) be completely demolished, but internal structure can be removed
– The existing foundations may need to be taken down to a lower level unless they are left in place behind a newly installed piled wall.
– There is limited headroom within the property unless internal floors are removed.
– Access for plant and removal of spoil is made difficult by limited access into and through the existing building.
– The site is within a residential area.
– Construction activities may affect the quality of the neighbor's life. The boundary walls may be shared with your neighbor (a 'Party Wall').

It is rarely the case that basements in urban areas can be constructed in open cut and it is therefore necessary to devise a suitable scheme to support both the existing structure and retain the ground. It is also necessary to be able to assess the ground movements that may occur while the work is in progress and the effect that these may have on surrounding structures. On large plots of land the simplest solution for the construction of a basement under the house is to re-support the house on piles or underpins and construct the basement around it within a piled wall. It is not often feasible or economic to do this. For smaller plots the preference is always to maximize the available space within the plot. This mitigates against most sorts of bored pile walls because clearance from existing boundary walls to construct these and a capping beam means that this generally loses a minimum of around 900 mm all the way round the basement in plan. In any case, headroom even for small piling rigs (normally around 2.5 meters) is often not sufficient to work inside buildings without carrying out substantial internal demolition. Thus, the solution is often to use underpinning inside buildings, whilst using piling techniques outside. Space can be maximized outside by using such techniques as 'jacked-in' steel sheet piles where ground conditions are suitable.

The construction of deep conventional underpins (i.e. the extension of existing footings downwards by excavation of the ground by hand) is time consuming and needs to be done with great care if ground movements are to be kept to an acceptable level and local damage avoided. If foundations and ground conditions are poor, the settlement that may occur as a result of the operations is difficult to predict as it is impossible to determine how load is shed between different parts of the walls as the underpinning progresses. There are a number of options that can be considered to reduce this risk, from pretreating the ground to strengthening the structure or providing temporary vertical support during underpinning using piles attached to a ring beam. The solution adopted is based on a detailed understanding of the actual conditions and an assessment of the risks, rather than an attempt to calculate what may actually occur while the work is in progress. Although a calculation can be done which assesses the effect of taking off the foundation load and transferring it to a lower level, the resulting settlement is only a part of settlement that may actually occur. The selection of a suitable method is therefore as much a matter of judgment and experience as of anything else.

The installation of piles or the construction of underpins will cause ground movements, not only immediately under and around what is being constructed but also over a wider area. There is a limited data base of information on the effects of installing bored pile walls in London conditions but no data on the effects of installing conventional underpins. Again, these effects are not susceptible to analytical analysis and it is generally the case that any damage to adjacent structures that occurs is not as a result of the wider scale movement which tends to result in only small ground strains, but as a result of localized movement which occurs because of poor near surface conditions or poor construction control.

Once retaining walls have been constructed the process of construction is more controllable and predictable and the possible effect of construction can be modelled in order to make predictions of both the behavior of the walls and the movement of the ground within and outside the basement. If a multi-stage underpinning process is adopted with ground levels within the basement lowered between stages of underpinning, the effects of the underpinning will have to be superimposed on such an analysis. It is very debatable, however, what the benefits of doing detailed analysis are when movements are generally small and general predictions of movement can be based on empirical evidence. This, of course, depends on the scale of the basement, the sensitivity of the surroundings and whether critical conditions can be realistically modelled. More often than not, in London, once the depth of dig exceeds around 6 meters below existing floor level, such analysis may be worthwhile. The critical matter is the early installation of effective support to the retaining walls at a very early stage in order to restrict lateral movement at the ground surface behind the wall and therefore limit the development of any horizontal strain in the adjacent buildings.

The effect of movement of the ground on adjacent structures is very dependent upon the actual situation and each development needs to be considered on a case by case basis. For example, if it is proposed to construct a basement under one house which is in the middle of a row of houses (known as a 'terrace' in the UK), the front and rear walls of the property act as constraints to lateral movement of these facades, resulting in largely shear distortion, Internal cross walls may not have the same lateral continuity because of staircases running up through the buildings and therefore not provide the same constraint. The same factors will not apply if the basement is constructed under a property at one end of such a terrace or one half of a house (known in the UK as a 'semi-detached' house), but lateral movement of the common wall can be controlled by restricting the movement at the top of the retaining wall. Where the basement wall is constructed at a short distance away from the side wall (in the case of 'detached' of a nearby structure) the same degree of control of lateral movements cannot be exerted.

Techniques used for domestic developments cover the full range of geotechnical processes, as can be imagined. These include permeation grouting, jet grouting, ground water control, jacked arches and all types of piling. The difference between this and larger commercial projects is simply a matter of scale and the difficulty of working in confined spaces.

The process that is in place in the UK to control development and protect those affected by basement construction is embodied in the legislation that controls Planning (i.e. whether or not such a development is permitted by the Local Authorities) and Construction. The latter falls under the Party Wall Act which requires the developer to agree with the owners of the adjoining properties on the construction process and how it is controlled and to agree that costs incurred by the adjoining owner, including the cost of repairs caused by damage, are met by the developer. This only applies when a structure falls within a specified zone defined by the geometry of the new construction. The Planning Laws require the developer to demonstrate that the proposed scheme will not do any damage to adjoining properties. In terms of structural damage due to basement excavation this is broadly interpreted as meaning that cracking may occur (as it is impossible to dig a basement without causing movement and any movement may cause a crack) but that the damage should not fall into the category where it may impair the structural performance of the building. This is generally taken as being defined by the table attributed to Burland (see Gaba et al. (2003)), i.e., damage should be no greater than the 'slight' category. The detail of assessment of the effects of basement construction varies considerably from one Local Authority to another. In London, in the wealthier boroughs, the bar is set high and the developer is required to look in detail at the principal risks, mainly the environmental impact and the potential damage. Part of the environmental impact is the effect on ground water. This is particularly relevant in areas where there is a significant change in elevation and the basement structure can impede ground water flow. The effect of basements construction on ground water recharge is also an issue.

There is some concern from the residents of London Boroughs that basement schemes can get through the Planning process too easily and that, once they do, the controls exerted under the Party Wall Act are not sufficiently stringent to prevent potentially damaging schemes from being constructed. The problem that is mainly of concern relates to the quality of the work, both in terms of design and construction, as the method of working can be broadly defined under the Planning consent in terms of a construction plan. This has resulted in an attempt to tighten up the Planning Laws to deal specifically with basement construction and to limit the scale of such developments. To date this attempt has been unsuccessful and curbs on basement development have to be fought for by local residents at the Planning stages by coordinated attempts to block schemes. This is costly for all concerned.

Under the Party Wall Agreements that have to be in place before the critical elements of work can be started, the engineering advisors for the respective parties have to agree that the method of working and design are satisfactory and, more often that not agree a monitoring regime which provides a check on actual performance. This is important because of the difficulty of making predictions about what may occur. It is fairly common for such agreements to be based on a maximum predicted level of damage of 'very slight' rather than the 'slight' used as the criterion for Planning. This discrepancy is clearly an issue for those likely to be affected by such developments and reflects the fact that the Planning and Party Wall Awards are two stages in a process. In the case of these domestic developments the Owners do not wish to spend large amounts of money at an early stage without some certainty that what is being proposed will be allowed to proceed. Hence, the Planning process normally does not develop proposals beyond a point where the impact can be broadly assessed.

It is now commonplace to undertake detailed monitoring of the movements of ground and structures on domestic basements. The trigger levels are generally set to limit damage rather than being related to the performance of the support systems. The 'red' trigger levels will be set at around 10 mm for any movement for this reason, and the 'amber' trigger levels are set just below them so that some forewarning is given of the approaching upper level, which would give the adjoining owners the right to insist that work stops.

3 COMMERCIAL DEVELOPMENTS

It is difficult to draw a clear distinction between domestic and commercial developments when it comes to substructure, but there are some differences which have an important effect on the way a development may be approached. These are:

- Planning issues. Commercial developments may involve a dramatic change to the local environment in terms of aesthetics and usage and the Planning issues are centered on this aspect rather than the issues of nuisance and damage which dominate the Planning issues for domestic basements.
- Scale of site. Sites are generally larger, affecting a larger area.
- Financial aspects. A commercial development scheme will evolve in a different way to one financed by a householder, both in terms of what the developer is prepared to invest up front to get the scheme to the point where construction can start and the cost of the design work that needs to be done.
- Depth of basement. Significant commercial basements, which often require a large number of car parking spaces and areas for plant tend to have deeper basements.
- The nature of the foundations. One of the principal differences between the domestic and commercial developments is that, for the former, the loads applied by the new structure are not large and do not change significantly from the loads applied by the old structure. Often for domestic basements many of the loads are applied on the old foundations. With new commercial developments the building height may be much greater than that of the existing structure and the loads applied in a completely different place. With large column loads foundations need to be taken on deep piles installed before the basement is constructed. This requirement may dominate the construction sequence.
- Site history. Commercial buildings in urban areas are often on sites that have previously had developments on them in the past. As already mentioned these may take the form of things of archaeological interest, but may take the form of an existing basement and or substructure. The historical nature of city centers also impacts in that the site may be adjacent to particularly sensitive old structures (e.g. old churches).
- The nature of the surrounding structures. It is, despite the exceptions mentioned above, more often the case for commercial developments that the surrounding structures are more robust than domestic properties. Hence it is not so necessary to control movements of the ground in the early stages of basement excavation.
- Surrounding infrastructure. Commercial buildings are more likely to be adjacent to significant infrastructure (tunnels, water and gas supply, waste water, railways) and therefore more likely to have constraints imposed on them because of the impact that they may have on what is in place. The proximity to heavily trafficked or critical roads may also be of significance.

Commercial schemes generally have a much longer gestation period than domestic developments because of the scale of the Planning issues. From the engineering perspective the initial review of a scheme will normally include a broad assessment of the principal risks in the ground based on desk study information. There is often sufficient information on ground conditions at this stage to be able to form a view on the geotechnical design. Such a desk study must identify, in as much detail as possible, the constraints to the development. This involves defining the likely zone of influence of the proposed works and then collecting all information on the surroundings from the stakeholders (i.e. owners of the properties, services and highways) that may be affected by the scheme. Often these stakeholders have statutory rights which impose stringent limits with regard to both the proximity of any construction and the requirements to demonstrate that their assets will not be affected. This information assists the design team in making decisions concerning scheme feasibility and scope and feeds into the project costing.

Critical questions that are addressed at this time are on a very broad basis. With respect to the sub-structure they include:

- Is there anything of archaeological interest in the ground? If there is, what impact does this have on the form of the development, the cost and the program?
- What form could the basement/substructure take in order to provide the space required? It may be better to have a deeper basement over part of the site where third parties are not likely to be adversely affected.
- How does the existing substructure impact on the new foundations and basement?
- What are likely to be the practical options for the construction process bearing in mind the possible impact on the surroundings?
- What are the opportunities in the ground in terms of sustainability.

Increasingly, the consideration of what is already in the ground is one of the key items in the decision making process as this may present either an opportunity (in terms of direct benefit and sustainability) or a risk. Existing basement structures and foundations are often reused either piecemeal or in their entirety, but they may have a very limiting effect on the development in terms of basement space and foundation capacity. The ideal situation is one where the entirety of the substructure and even the lower floors of an existing building can be reused, with the requirements for local load increases being addressed by the threading of new piles through the exiting foundations to provide stiff supports that will attract the additional load. The effort required to remove major substructures is often enormous and the deepening of existing basement structures, although feasible, often involves complex temporary works. Existing foundations are rarely ideally placed to be reused and often form an obstruction for new foundations. The option of removing piles in order to construct new piles is a more realistic one than it was 10 years or so ago. However, opportunities do arise for reuse and it is necessary to approach them with a flexible attitude because they rarely present a simple solution. They need to be carefully explored, but initial optimism is often quashed by the complexities of both the additional design work required and the realities of the construction.

The answers to these questions should form an integral part of the early scheme design and the geotechnical professionals need to be a part of this process.

At this stage a scheme has been brought to the point where it can be presented to the Planning Authorities for approval. Those likely to be affected by the proposals will be made aware of what is planned and given the opportunity to raise any concerns that they may have. This is the point at which detailed information is collected and discussions are initiated with the third parties. This enables the options identified during the initial stages to be developed in more detail by the construction professionals. These discussions are often dominated by the desire to find a practical method of construction which minimizes the construction period. In a confined site with a basement structure this means finding solutions which minimize constraints to excavation and construction whilst ensuring that ground movements caused by construction are acceptable. This is a difficult compromise which can be assisted by detailed analysis together with experience.

In contrast to the situation for domestic basements it is often possible to allow some horizontal movement at the head of a basement wall during the early stages of excavation, for example if a site is largely surrounded by roadways. Although a limit is likely to be imposed, this means that the excavation can be taken down well below street level without having to provide supports in the form of props or anchorages to the wall. This leaves an open site at a low level from which piles can be installed and gives the opportunity to remove near surface obstructions unimpeded by temporary supports. This can be achieved by using anchorages if these are permitted (which they are generally not in London because of the perceived risk of drilling through made ground on the roads above). Novel approaches to the problem can be found, but without a means of being able to analyze them, they can be difficult to justify.

Complex geotechnical analysis can be used to predict the likely behavior of different support systems, but it would be unrealistic to pretend that such predictions can be made with a high degree of accuracy especially for walls which are entirely supported by the soil (i.e. the walls act as cantilevers) rather than by external supports. One approach is to demonstrate the potential improvement offered by a support system in comparison to one that is more widely used and documented in terms of movement. It is often necessary to carry out such analyses to demonstrate that such a scheme is structurally acceptable.

An example of such an analysis is one analyzing the incorporation of deep bearing piles in front or behind a capping beam for a bored pile wall. Three dimensional finite element analysis can be used to model a section of the wall and a pile and the capping beam and look at the additional constraint that the bearing piles provide. It can also be used to look at the stresses induced in both wall and piles as a result of excavation and the addition of the vertical loads from the superstructure.

It becomes easier to predict wall behavior and ground movement once internal supports are installed as the stiffness of the internal supports is more easily defined than the reaction of the ground to excavation. Often it is sufficient to simplify models of excavations to two dimensional problems and supports to simple springs. However the ability to model complex geometries of both soil and structural support is improving all the time and such advances can provide real advantages in terms of demonstrating that structures can be made to work and that movements of the surrounding ground are not as great as the simplified analyses would predict. Increasingly it is becoming more practical in terms of both time and cost, to do modelling in three dimensions, particularly with certain categories of problems.

One of the problems of relying on complex modelling to justify the approach being taken to design or construction is that the results of such modelling can normally only be checked by carrying out modelling of similar complexity. Independent checks are normally required in the case of critical assets, such as railway tunnels where public safety is an issue and the costs are large if use has to be restricted, e.g., trains cannot run. This is part of the validation process which is normally captured in parallel with the preparation of the 'Party Wall Awards' which have to be signed by all parties before work commences. On complex projects these preconstruction agreements cover different stages of construction, e.g. demolition, groundworks and superstructure works in order to be able to proceed without having to fully define the project works. This may mirror the way the contracts are awarded for the different phases of the project.

As with the domestic developments monitoring forms an integral part of the construction procedure and it is not uncommon to adopt the same ‘traffic light’ approach to control. The results of any modelling, together with experience, inform the trigger levels that are adopted as well as the method and frequency of measurement. The philosophy adopted for the trigger values depends on a number of factors and it depends which of these is critical. With deep basements the critical measurements are often those of the movement of the retaining walls (using inclinometers) as these are the best indicators of how the support system is working. Generally if the predicted lateral movements fall within the range of expected behavior, movements outside the basement area are likely to be acceptable. The main exception to this is during the early stages of construction (before retaining walls are installed) when the potentially damaging activities are those that can cause local effects and therefore large local strains to adjoining structures. An example of this is the installation of piles in poor ground conditions. The effective design of a monitoring system and choice of trigger levels therefore takes into account the risks at different stages of the works, designs a robust monitoring system that provides the critical information at each stage and sets appropriate trigger levels for both stages and measurement points. It goes without saying that the critical element of any monitoring system, apart from robustness, is the way in which the data obtained are handled. On large projects sufficient resources can be dedicated to the treatment and dissemination of data, but this is not always the case and it is not uncommon for trends in behavior to go unnoticed before a critical point is reached.

4 CONCLUDING REMARKS

As geotechnical engineers we work with a large group of professionals and our role is to ensure that, at all stages of a project, the team is made aware of the risks and opportunities that our own discipline presents. This needs us to be able to provide informed opinion about construction processes as well as an ability to use the appropriate analytical tools and know when (and when not) to use them. In the case of the smaller domestic basements there is much more reliance on the experience, skill and care of the specialist contractors than on our ability to model what may happen. With larger commercial projects the skill set is different, but attention to detail is just as important and as city centers are redeveloped and reuse of existing substructures becomes more frequent, we need to keep a careful eye on this new problem and be aware of what can be achieved with some ingenuity.

REFERENCE

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