Deep Excavations in Glacial Tills in Dublin

Deblais profonds dans les Moraines glaciaires de Dublin

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ABSTRACT
A number of Deep Excavations up to 23m in depth have recently been completed in Dublin. Different approaches including propped and unpropped, Secant and Contiguous Pile Wall Solutions have been employed on various projects. The paper updates a database for propped and cantilevered wall supported excavations in Glacial Tills. A comment and interpretation of recorded wall movement versus retained heights and wall stiffness is provided. Modelled predications are also discussed. Two case histories of deep basement excavations including Spencer Dock in the Docklands, 14m excavation at Westgate (Heuston Square) and other projects are presented and discussed.

RÉSUMÉ

Plusieurs excavations jusqu'a 23m de profondeur étaient construit récemment a Dublin. Des méthodes différents en compressant des murs de soutènement avec ou sans butons, pieux sécants ou jointifs ont été utilise sur des divers projets. Un commentaire et un analyse des mouvements enregistrés par rapport avec l'hauteur de soutènement et la raideur du mur de soutènement sont donnes. Les prédictions de la modélisation sont discutés. Quelques ouvrages avec des fouilles profonds à Dublin, Irlande, sont présentés et sont examines.

Keywords :

1 INTRODUCTION

The recent period of sustained economic growth in Ireland has led to an increase in the use of underground space, with some development now including 4 underground levels. The purpose of this paper is to provide an update on recent developments in deep excavations in the Dublin area. Specifically the paper will:

- Present recent developments in the use of retaining walls.
- Present current approaches for the design of deep excavations by reference to some case histories namely:
  - → 14 m excavation at Westgate supported by a single row of anchors
  - → 7 m deep excavation in complex ground conditions at Spencer Dock in Dublin docklands.

2. BACKGROUND GEOLOGY

Bedrock in the Dublin area is a thin to medium interbedded homogenous grey argillaceous limestone and calcareous shale. Over much of the city, it is overlain by glacial deposits, known colloquially as Dublin boulder clay (DBC). This is hard lodgement till which was deposited beneath the ice sheet that covered much of Ireland during the Pleistocene period. This till is a very dense / hard low permeability deposit, which contains pockets of lenses of coarse gravel, particularly at depth. Oxidiation of the clay particles in the top 2 m to 3 m has resulted in a change in colour from black to brown and a lower strength material. Geological conditions in the Dublin docklands are complex and comprise a series of estuarine clays, slits, sands and gravels. The situation in the docklands area is complicated by the presence of a pre-glacial channel just north of the River Liffey. It has significant importance in that is it generally filled with deposits of glacial and fluvio-glacial gravels.

Figure 1. Tallaght Town Centre

3 UPDATED DATABASE FOR PROPPED WALLS

Looby et Long (2007) produced and updated a version of the 2001 database (Long, 2001) for propped walls in competent glacial deposits augmented with data from eight additional sites including the 14 m deep Westgate excavation, 12m deep talllaght (figure 1) and data from the Dublin Port Tunnel project where excavation depths were up to 25 m. Generally all δ_h values are less than 10 mm. There does appear to be some weak tendency for an increase in δ_h with H (reference Figure 2). The database indicates normalised movement (δ_h/H) was typically less than 0.18%. The former relationship was obtained by Long (2001) for an average of 169 case histories worldwide where there was stiff soil at dredge level. The behaviour of the Dublin projects is significantly stiffer than the worldwide average. The 0.4% line represents a typical design value as recommended by CIRIA report C580 and clearly this relationship is very conservative for the Dublin cases.

This data takes no account of the retaining wall type, its stiffness nor the prop / anchor configuration. In order to attempt

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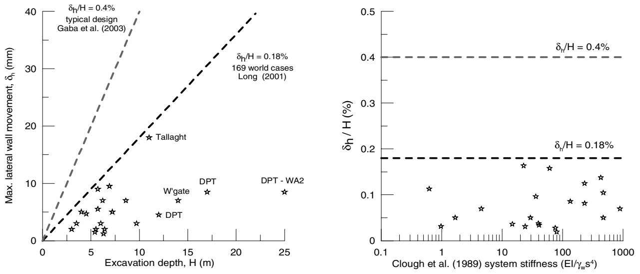

Figure 2. Dublin glacial till database for propped walls (a) $\square_h$ versus H (b) δ_η / H versus EI/$\gamma_\omega s^4$

to include these factors, looby et al replotted the data normalised form of δ_h/H against Clough system stiffness. Lateral movements appear to be independent of stiffness. This suggests that a more flexible (and hence a more economic) wall may perform adequately in many cases.

4 RECENT DEVELOPMENTS IN CANTILEVER WALLS

4.1 Cantilever walls worldwide

Looby et Long (2007)presents a summary of cantilever case histories, which is an expanded version of the one given by Long (2001). For the stiff soil at dredge cases, surprisingly, the δ_h values are confined to a relatively narrow band certainly up to a retained height of about 9 m. δ_h values are on average about 15 mm (reference Figure 3). Beyond H = 9 m, there is a tendency for increasing δ_h. The average δ_h/H is about 0.25%.

4.2 Cantilever walls in Dublin

Relatively high cantilever walls have been used for some time in Dublin. Use of these walls was based on the practical experience of open cuts in the glacial tills being able to stand unsupported at very steep angles. More recently cantilever walls of 7.5 m or so are being used regularly. An example of the 7.5 m high cantilever 600 mm diameter contiguous pile wall at Hunters Wood, Ballycullen Rd. is shown on Figure 4.

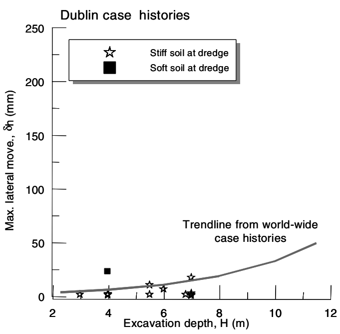

Figure 3. Cantilever retaining wallsδ_h versus H world-wide case histories Dublin.

Figure 4. 7.5 m high cantilever wall at Ballycullen Rd. in service September 2007

The Dublin walls have performed very well, with values falling in general well below worldwide movements. Average δ_h and δ_h/H values are about 5 mm and 0.08% respectively. An exception is the Thorncastle St. case history (Long et al., 2001) where there was soft alluvial soil at dredge level. It seems that lateral movement is independent of system stiffness and once a sufficiently stiff system is provided the walls will behave well. Again it seems Irish practice is conservative and perhaps even more conservative than that worldwide. Based on these data it seems there is scope for the use of higher cantilever walls, at least for temporary wor s purposes.

4.3 Behaviour with time

The data presented above omit one very important factor, i.e. how does the lateral movement vary with time. This has important implications as to whether these walls can be used for permanent work as well as temporary works and also in the temporary case how long is the useful life span. Data from five sites all in glacial till and Thorncastle St. in soft alluvial soils are shown on Figure 5. The data for Ballycullen Rd is of particular interest as it spans a period of some 140 weeks (2.7 years). In most of the projects, after a relatively short time, the retaining wall was encorporated into the permanent works. It can be seen that in all cases there is a gradual development of movement increasing with time. For the glacial till cases the rate of increase of lateral displacement is relatively slow. However for the soft alluvial soils case at Thorncastle St the development of movement is rapid.

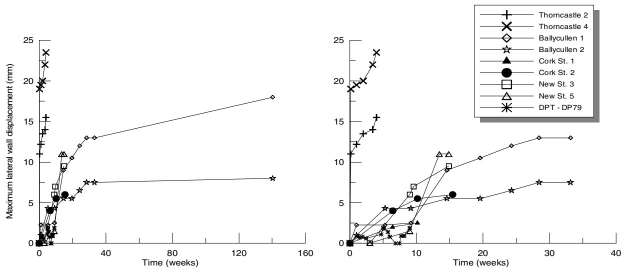

Figure 5. Cantilever retaining wall movement with time

The reason for this behaviour is the gradual dissipation of negative pore pressures (suctions) and the build up of positive pore pressure, which is discussed in more detail in Looby et Long (2007) and outside the scope of this paper. The excavation-induced stress relief, means that pore pressure (u) reduces and, depending on its initial value, could become negative. If u reduces then the effective stress increases. The length of time over which this reduced pore water pressure can be sustained is a complex issue and depends on the soil type, its fabric, permeability, the sequence of construction, slope protection, weather, etc.

5 DESIGN APPROACH

From a practitioners point of view in order to understand why low level deflections in retaining walls in boulder clay are occurring it is important we understand the background to retaining wall design. The following section briefly outlines some of the modelling issues critical to wall movement. After horizontal or vertical unloading theoretical soil and groundwater pressures in cohesive soils can be significantly less than zero and can sometimes provide no active load on a retaining wall. This will be further discussed below. For a number of reasons this is not an acceptable including tension cracks and potential unidentified pockets of sand and gravel could provide loading conditions and failure modes that tend towards effective stress conditions.

In order to account for the above criteria in retaining wall design BLP currently use one of the following approaches (a key factor in which approach is employed is the level of the groundwater for the particular project).

- Effective stress conditions with a low K_a value
- Undrained soil parameters with a minimum equivalent fluid pressure employed in the analysis as per CIRIA C580.
- Undrained soil parameters with full hydrostatic groundwater pressures
- A combination of the above criteria

The above paragraphs outline conditions that can occur and the relevant design criteria. In reality, actual loading conditions on the wall could be closer to the undrained or partially undrained conditions where complex (including negative) pore pressures exist. This results in low or zero lateral pressures on the wall. Obviously the deflection predictions from the analysis with undrained parameters will be significantly less than any of the design approaches discussed above.

The use of undrained parameters in conjunction with the observational approach may be considered for reducing predicted deflections to simplify the construction sequence and reduce costs. (In addition to this, how use of “we” groundwater is modelled with time post excavation should also be considered but is not addressed as part of this paper). This approach should also only be considered where the predicted deflections using traditional approaches are within defect limits to prevent the possibility of damage, economic loss or unsafe situations. The risk associated with the decision should be clearly assessed in terms of understanding of the site geology, type and condition of structures to the rear of the pile wall and the quality of monitoring procedures put in place. This decision to use undrained parameters will have a large impact on predicted deflections as discussed above.The benefits of using undrained parameters are not so much that pile sizes will be reduced but that more cost effective overall solutions can be employed in more areas. It seems there is scope for the greater use of cantilever walls and also greater retained heights at least for temporary works purposes.

Similar design issues arise in relation to undrained soil parameters on the passive side of the wall and undrained analysis can potentially allow for very shallow embedment depths. In order to allow for the possibility of unknown gravel layers, effective stress parameters are often used to determine the overall stability requirements. However the serviceability analysis may require the benefit of using undrained material on the passive side in order to more accurately predict deflection. A summary of the critical issues in relation to retaining wall deflections and predictions are as cohesive or cohessionless model – in conjunction with how we model groundwater with time, continuous call (secant/sheet pile) or contiguous, surcharge propped/cantilevered, groundwater conditions, soil parameters – quality of investigation and Attitude to risk

6 CASE HISTORIES

The design and monitoring of two deep basements are described in the following sections. Both were completed in the past three years. The projects were selected to compare the performance of permanent and temporary, propped and cantilevered walls in various soils types and the accuracy of predicted deflections.

Figure 6. Westgate

6.1 *Westgate*

The Westgate Development (see Figure 6) is a combined commercial and residential development, adjacent to Heuston Station, south of the Liffey. Topographical levels on the site vary between 14m OD at the south end of the site and 6m OD at the north. Basement formation was 0m OD resulting in a 14m retained height at the southern end. Ground stratigraphy is illustrated in the geological x–section of the site as provided in Figure 7. Soil parameters employed for the different strata are as indicated in Table 1. Groundwater levels varied between +8m OD of the southern boundary and 0.9m OD at the northern boundary. Figure 21 illustrates a typical x-section through the pile wall.

Stratum	**Depth m bgl**	**E MPa**	**Ko**	**ϕ (°)**	**C_u**
Fill	0- 1	50	0.5	30	-
Dense Gravel	1-25	150	1	38	-
Stiff Brown Clay	1-25	150	1	35	-

Table 1. Westgate Soil Parameters

A key aspect of the retaining wall design was the use of the “Observational Approach” to monitor the movement of the wall as excavation proceeded to allow a lower level of anchors be ommitted. A strict monitoring and response action and geotechnical risk assessment was implemented as part of the excavation protocol. “Trigger level” lateral movement criteria was established prior to the works commencing for the different stages of excavation.

6.2 Recorded Movement

Figure 8 illustrates a typical x-section showing the original predicted deflection and the recorded pile inclinometer data. The original analysis included modelling the soil stratigraphy with drained parameters using both FREW and PLAXIS analyses. In the PLAXIS analyses the made ground and glacial soils were assumed to behave as elastic perfectly plastic materials with failure defined by Mohr Coulomb using drained parameters. The analyses gave reasonably consistent predictions within 20% of each other. The original design analysis predicted pile deflections of 50mm. Maximum recorded pile deflections were 12mm. The modelled movements are significantly different. It is noted also that while the original Site Investigation suggested that significant gravel layers may be present, inspection of the bulk excavation at the southern end of the site indicated the soil was predominantly a clay material.

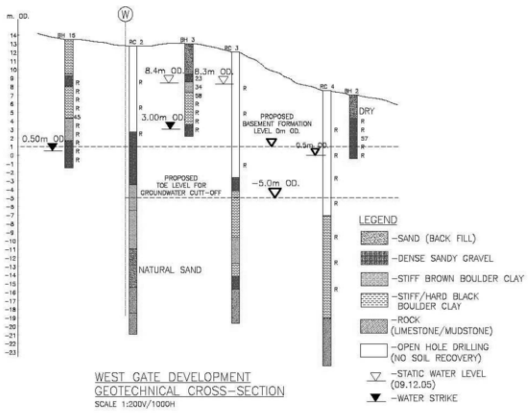

Figure 7. Westgate Geological Section

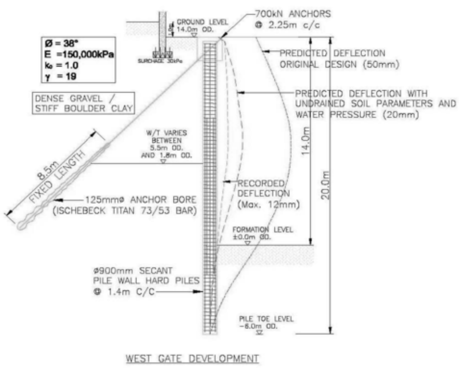

Figure 8. Westgate Pile Section

Figure 8 also indicates the results as analysis of the wall with undrained soil parameters and a static water level 7m OD was carried out using FREW. Predicted pile deflections were 20mm suggesting that the undrained parameters would model actual pile deflections more accurately. Figure 8 also indicates the predicted pile deflection profile using the drained parameters. The introduction of a consolidation stage in the analysis to model groundwater pressures with time may further improve predictions.

6.3 *Spencer Dock*

Spencer Dock (see Figure 9) is located in the Dublin Docklands and is 2km east of the city centre adjacent to the River Liffey. Topographical level at the site is +2.5m OD. The site is bounded to the west by the Spencer Dock canal and the south by the River Liffey. The water table on the site is 0m OD and is not significantly influenced by the tidal cycle. The upper made ground consists of brick and masonry in a clay matrix. Due to the variable depositional environment in this section of the site close to the river, the alluvium stratum is a complex mixture of soil types typical of the docklands. The upper 3.5m comprises a loose to medium dense sand and gravel. This is underlain by a soft clay and silt with organic material. N-values in the soft clay layer vary from 2 to 7. The underlying glacial deposits consist of 2 to 3m of dense gravel overlying a hard till.

6.4 *Movement*

FREW was employed to carry out the original pile wall analysis and indicated that predicted pile deflections would be in the range of 35mm to 40mm. A sensitivity analysis was carried out at the time of the design varying the stiffness and strength characteristics of the soils as well as modelling the layer with drained and undrained parameters for the soft alluvium layer. Inclinometer readings over the course of the construction stage recorded the deflection profile as being reasonably consistent with modelled deflections, approximately 15% less as per Figure 9, illustrating that the model may be better at predicting movements in the cohesionless soil layers and low strength strata's as encountered.

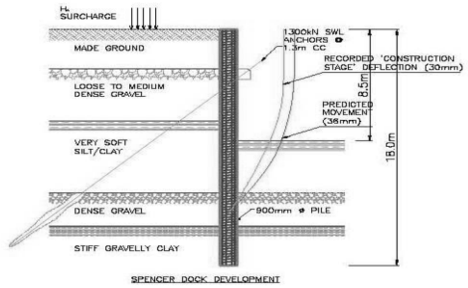

Figure 9. Spencer Dock Pile Section

7 CONCLUSIONS

1. Case history data confirms retaining wall behaviour in Dublin glacial till is extremely stiff. This applies to excavations up to 25 m deep.
2. It appears that current approaches over predict walls deflections and the use of overall current design practice is clearly conservative.
3. The use of undrained parameters in conjunction with the observational approach may be considered for reducing predicted deflections to simplify the construction sequence and reduce costs.
4. This approach should also only be considered where the predicted deflections using traditional approaches are within defect limits to prevent the possibility of damage, economic loss or unsafe situations.
5. Cantilever walls have been successfully constructed up to 7.5 m high. These walls show smaller movements than expected, though the development of movement with time is very important.
6. It seems there is scope for the greater use of cantilever walls and possibly also higher retained heights, at least for temporary works purposes.
7. Important insights into the above can be gained from observations of steep slopes in Dublin boulder clay, where pore water suction plays an important role.
8. Measurement of Pore Water Pressure to rear of walls should be carried out.
9. The analysis employed accurately predicted deflections in the boulder clay.

REFERENCES

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