

Deep excavation in Irish glacial deposits

Excavation profonde des dépôts glaciaires Irlandais

Long M., O'Leary F.

Department of Civil, Structural and Environmental Engineering, University College Dublin (UCD), Ireland

Ryan M., Looby M.

Byrne Looby Partners, Dublin, Ireland

ABSTRACT: A good number of deep excavations have been recently completed in Irish glacial deposits. These have included propped walls up to 12 m deep. Experience elsewhere in the world was used to design and construct these walls. However case history data has shown that the behaviour of these walls is very rigid and much stiffer than comparable systems worldwide. It appears this behaviour is due to the inherent natural strength and stiffness of the soil and the slow dissipation of excavation induced depressed pore pressures or suctions. There appears to be scope for developing more efficient designs and in particular for greater use of cantilever walls and less stiff systems with smaller piles and reducing propping requirements. For temporary works, the use of undrained parameters in serviceability limit state calculations together with implementation of the observational approach on site could be considered for future schemes.

RÉSUMÉ : Un bon nombre d'excavations profondes ont été récemment réalisées dans les dépôts glaciaires Irlandais. Elles ont inclus des murs de soutènement jusqu'à 12 mètre de profondeur. La conception de ces murs a été réalisée grâce aux méthodes utilisées dans les autres pays du monde. Toutefois, les analyses a posteriori ont montré que les caractéristiques de ces murs étaient extrêmement rigides et bien plus rigide que d'autres systèmes comparables dans le monde. Il semble que ces caractéristiques sont dues à la résistance naturelle et à la rigidité du sol ainsi qu'à la lente dissipation des pressions interstitielles déprimées ou aux suctions induites par la réalisation des excavations. Il semble y avoir des possibilités de développer des méthodes de conceptions plus réalistes et moins conservatives permettant en particulier une utilisation accrue des murs cantilevers et des systèmes moins rigides avec de petits pieux de fondation et en réduisant les besoins de butonnage ou d'ancrage. Pour les travaux temporaires, l'utilisation de paramètres non drainés dans les calculs des états limite de service ainsi que la mise en œuvre de l'approche observationnelle sur le chantier, pourraient être envisagées pour de futurs projets.

KEYWORDS: deep excavations; retaining walls; glacial deposits; ground movements

1 INTRODUCTION.

Over the previous 15 years, economic growth in Ireland has led to an increase in the use of underground space, with some development now including four underground levels. Valuable full scale data has been obtained from a good number of these projects. The purpose of this paper is to provide an overview of aspects relating to the design, construction and behaviour of retaining walls in Irish glacial deposits.

This paper will exclude projects located in the two main cities of Dublin and Cork. Case histories from these two locations have already been well documented (Long et al., 2012a; Long et al., 2012b; Long et al., 2012c; Long et al., 2013).

Specifically the paper will:

- Briefly review the background geology and ground conditions,
- Outline the presently used design approach,
- Review in detail the general behavior of walls in Irish glacial deposits by reference to two case histories namely:
 - lightly supported "regular" wall for 6 m excavation in Limerick,
 - 6 m excavation in Middleton, Co. Cork where a cantilever solution was used,
- Present an overall summary of the behavior of retaining walls in Irish glacial deposits compared to similar support systems worldwide,
- Provide some overall conclusions and recommendations for the design and construction of future similar schemes.

2 BACKGROUND GEOLOGY

Broadly speaking the coastline of Ireland is formed of strong older igneous and metamorphic rocks such as sandstones, granites and quartzite. The central basin of Ireland is formed of Carboniferous limestone. However the engineering geology of Ireland is dominated by the mantle of 10,000 to 15,000 year old glacial tills and glacial sands and gravels which cover much of the country. These deposits generally have a high gravel, cobble and boulder content and are usually medium dense to dense or stiff to very stiff in consistency. They form a thin layer (but usually greater than 3 m in thickness) draped over and conforming to the underlying bedrock topography. Later alluvial activity has covered the glacial deposits with soft clays, silts and peats in some low lying areas, in estuaries and along river flood plains (Edwards and Warren, 1985).

3 THE SITES

The location of the study sites is shown on Figure 1 and some details of the projects under consideration are given on Table 1. The sites are located throughout Ireland but mostly in the most populated areas to the east and south-east.

At each of the chosen sites inclinometers had been used to measure the lateral pile retaining wall movements. Details given on Table 1 include the depth of excavation (H), the support details including the spacing of the structural piles and the maximum measured pile deflection (δ_h max).

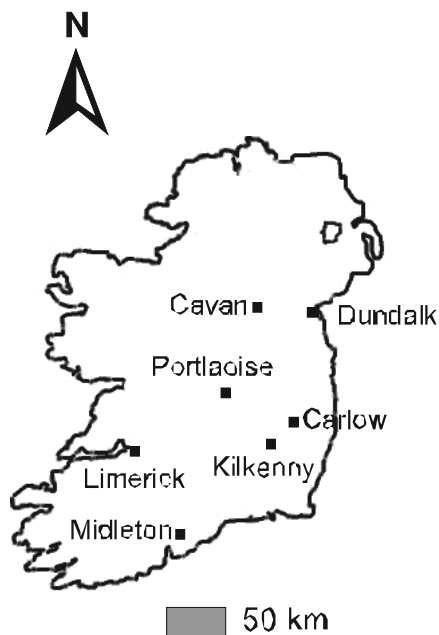


Figure 1. Location of study sites

Table 1. Details of study sites

Site No.	Location	H (m)	Support Configuration	Wall type
1	Savoy Limerick 1	6.4	Single anchor	Secant
2	Savoy Limerick 2	5.8	Single anchor	Secant
3	Main St. Cavan	9.0	Two anchors	Contiguous
4	Dundalk Cellar	8.7	Single anchor	Secant
5	Dundalk Bunker	8.1	Single anchor	Secant
6	Midleton Cantilever	6.0	Cantilever	Secant
7	Midleton Anchored	6.0	Single anchor	Secant
8	Kilkenny	7.7	Single prop	Contiguous
9	Kilkenny	6.9	Single prop	Contiguous
10	Shaws Carlow	5.0	Single prop	
11	Portlaoise SC Phase 1	12.0	Two anchors	Secant
12	Portlaoise SC Phase 2	7.0	Single anchor	Secant

Table 1 continued

Site No	Pile dia. (mm) / spacing (m) / length (m)	δ_h max (mm)	Reference
1	600 / 1 / 8.4	7	BLP files
2	600 / 1 / 7.8	2	BLP files
3	192 / 0.25 / 14	45	BLP files
4	640 / 1.4 / 10	6	BLP files
5	640 / 1.4 / 12	7	BLP files
6	640 / 1.2 / 16.5	27.5	BLP files
7	640 / 1.2 / 14	5.5	BLP files
8	600 / 0.75	5	Arup files
9	600 / 0.75	2	Arup files
10	n/a	2	NVM files
11	640 / 1.0 / 14	17	BLP files
12	640 / 1.0 / 7	4	BLP files

4 DESIGN

Current geotechnical design procedures for retaining walls in Irish glacial deposits often involves the following steps:

- Following the general guidelines of Gaba et al. (2003) or BS8002 (BSI, 1994), for ultimate limit state, determine the required retaining wall toe penetration. Calculations use effective stresses and are often performed by hand, using conventional Rankine active and passive earth pressure theory, or with a relatively simple piece of software,
- Check that this toe penetration is adequate to support any vertical loads and also to prevent significant water seepage,
- Determine wall bending moments, shears, prop / waler forces and lateral wall movements (serviceability limit state) by means of a beam – spring computer program such as OASYS – FREW[®],
- Determine the associated ground movements using empirical based methods, such as those developed by Clough and O'Rourke (1990). Possible adjacent building damage is then assessed by comparing parameters such as differential settlement with empirically based tolerable limits, e.g. those of Burland et al. (1977)

5 OVERVIEW ALL SITES

Data for the 12 available case histories are presented in Table 1. A plot of maximum measured lateral movement (δ_h) versus retained height (H) is shown on Figure 2. Except for the Main St. Cavan, Portlaoise Phase 1 and the Midleton cantilever excavations, δ_h values are less than 7 mm. There does appear to be some weak tendency for an increase in δ_h with H.

Also shown on Figure 2 are lines representing normalised movement (δ_h/H) of 0.08% and 0.4%. The former relationship was obtained by Long et al. (2012a) for projects in Dublin boulder clay – a very stiff glacial lodgement till. The behaviour of the projects presented here is similar if not better than the Dublin sites. The 0.4% line represents a typical design value as recommended by Gaba et al. (2003) in CIRIA Report C580 and clearly this relationship is very conservative for most of the cases presented but is consistent with the data from the Cavan and Midleton cantilever sites.

The data shown on Figure 2 takes no account of the retaining wall type, its stiffness or the prop / anchor configuration. In order to attempt to include these factors, the data are replotted on Figure 3 in the normalised form of δ_h/H against Clough et al. (1989) system stiffness. This is defined on Figure 3 where EI = wall stiffness, γ_w = unit weight of water (so as to make expression unitless) and s = support spacing.

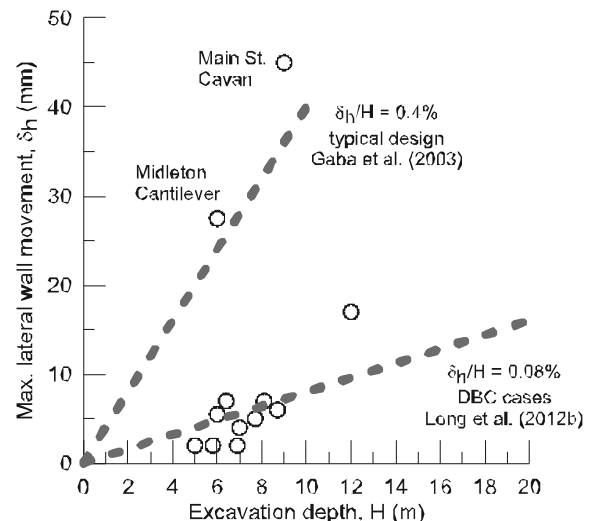


Figure 2. Maximum lateral wall movement versus excavation depth

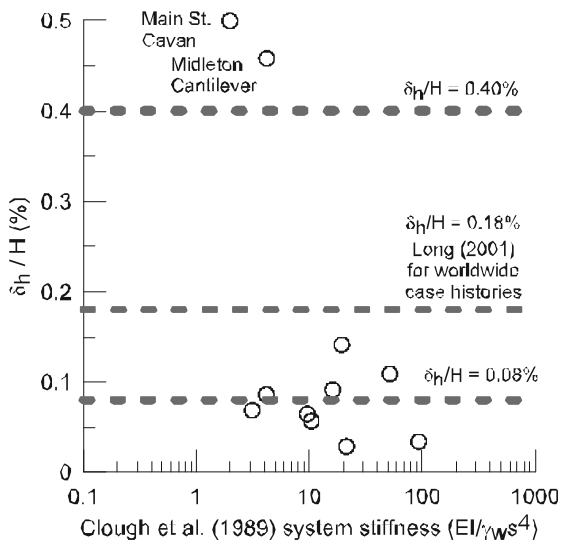


Figure 3. Normalised maximum lateral wall movement versus Clough et al. (1989) system stiffness

The two relationships included in Figure 2 are also shown here. In addition the relationship $\delta_h/H = 0.18$, which was obtained by Long (2001) for an average of 169 case histories worldwide where there was stiff soil at dredge level, is also shown. Lateral movement is clearly a function of system stiffness with the two walls with low system stiffness showing relatively high movements. The Cavan wall had very slender piles and the Midleton wall had no props or anchors. However the remaining data plot well below the worldwide trend suggesting that a more flexible (and hence a more economic) wall may perform adequately in many cases.

Some of the trends shown on Figure 2 and 3 are explored further by examining two detailed case histories as follows

6 CASE HISTORY OF A LIGHTLY SUPPORTED “REGULAR” WALL – SAVOY, LIMERICK

Details of this site are shown on Figure 4. The approach and techniques used at the Savoy Site are typical of those used at many sites in Ireland. The site is underlain by about 2 m of made ground over about 5 m of glacial deposits over limestone bedrock. The glacial deposits have standard penetration test (SPT) N values increasing from about 20 blows / 300 mm near the top of the stratum to an average of 60 blows / 300 mm with depth.

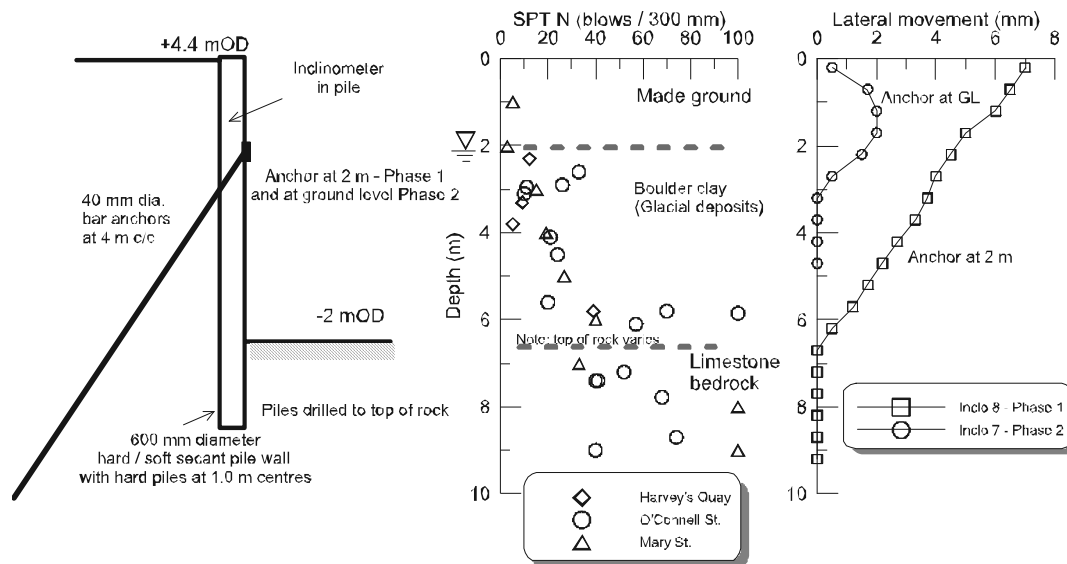


Figure 4. Savoy, Limerick

The retaining wall was required for temporary works purposes only and comprised a 600 mm diameter “hard / soft” secant wall with a single anchor. For the Phase 1 excavation the anchor was located at about 2 m depth. Much of the 7 mm or so movement recorded occurred while the wall was acting in a cantilever mode during the installation of the anchors. This is consistent with the findings of Long (2001) for a good number of world wide projects. Thus for Phase 2 the anchor was relocated to ground level and the measured movements were much smaller.

It would seem that a less stiff system, e.g. smaller diameter / more widely spaced piles or a cantilever wall would have performed perfectly adequately in this case.

7 CASE HISTORY OF CANTILEVER WALL

Details for the Midleton site are shown on Figure 5. This project was carried out in 2012 and thus many of the lessons learned over the previous 10 to 15 years could be used. Again the wall was required for temporary works purposes. It comprised a “hard / firm” secant pile wall with 640 mm diameter structural “male” piles and 900 mm diameter “female”. A single anchor was used at locations where sensitive adjacent buildings were present. However for non sensitive areas of the site and based on the experiences listed above a cantilever solution was used.

Ground conditions are more complex than those at Limerick and comprised a variable sequence of glacial clays, silts, sands and gravels. SPT N values increase from about 10 blows / 300 mm at the surface to an average of 25 blows / 300 mm at 7 m depth and thereafter remain approximately constant.

As would have been expected from previous experience measured movements for anchored section were very small. For the cantilever sections the wall also behaved very well and maximum lateral movements were of the order of 20 mm

Predicted wall deflections, using FREW[®] for the anchored wall are also shown on Figure 5. The key input parameters are the effective friction angle (ϕ'), the undrained shear strength (s_u) and the Young's modulus (E_u or E'). These were determined from correlations with SPT N. For the clay layers it was assumed $s_u = 5N$ and $E_u = 750N$ (Gaba et al., 2003; Stroud, 1988). For the granular soils E' was assumed = 2500N and ϕ' was found from the relationships of Peck et al. (1974).

It can be seen that the predicted values considerably overestimate the measured ones. A similar finding was made for the cantilever wall at Midleton.

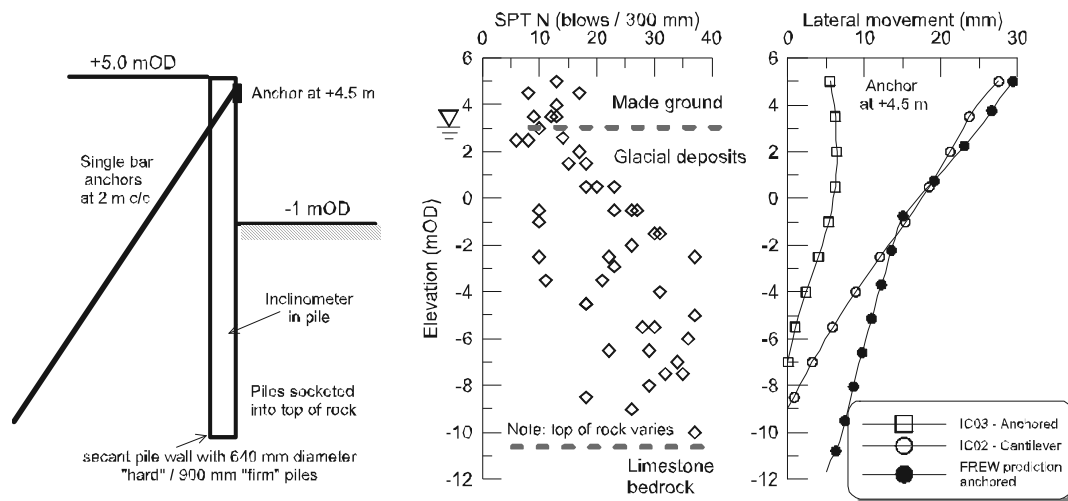


Figure 5. Midleton

8 DISCUSSION

The reasons for the very stiff behaviour of the retaining walls in Irish glacial deposits are complex but are due to a combination of the following factors:

- Excavation induced depressed pore pressures (or even suctions) in the material. These result in increased effective stress and hence stability (Long et al., 2012a).
- The low permeability of the clay fraction of the material (10^{-10} m/s or less) meaning that the dissipation of the depressed pore pressures takes a long time.
- The material has extremely high strength and stiffness.

A possible approach for the design of temporary retaining structures in the clay fraction of the material may be in the use of undrained parameters in conjunction with the observational approach. This approach should only be considered where the predicted deflections using an effective stress approach would be 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 and contingency measures put in place.

It seems there is scope for the greater use of cantilever walls, less stiff walls (e.g. smaller diameter piles) and also greater retained heights at least for temporary works purposes. It must also be emphasised that an effective stress design approach is always needed for the ultimate limit state analysis in permanent works as the suctions will eventually dissipate.

9 CONCLUSIONS

Case history data confirms that retaining wall behaviour in Irish glacial deposits is extremely stiff.

The reasons for this stiff behaviour lie in the low permeability and high strength and stiffness of the material and the resulting very slow dissipation of depressed excavation induced pore pressures.

It appears that the current approach, for serviceability limit state calculations, which usually involves beam – spring type computer programs is clearly conservative.

For temporary works, 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.

There is scope for greater use of cantilever walls and walls and systems with lower stiffness.

10 ACKNOWLEDGEMENTS

Some of the data used in this paper was kindly provided by Mr. Tony O'Dowd of PJ Edwards & Co., Mr. Pat Fox of Murphy International Ltd., Mr. Patrick Casey of Arup Consulting Engineers and Mr. Eddie Meade of NVM Ltd. and their co-operation is gratefully acknowledged.

11 REFERENCES

- BSI, 1994. *Code of practice for earth retaining structures*
- Burland, J.B., Broms, B.B. and De Mello, V., 1977. Behaviour of foundations and structures, *Proceedings IXth International Conference on Soil Mechanics and Foundation Engineering*, Tokyo, pp. 495 - 546.
- Clough, G.W. and O'Rourke, T.D., 1990. Construction induced movements of in situ walls, *Proceedings ASCE Conf. on Design and Performance of Earth Retaining Structures*, ASCE Pub. No. 25, Cornell, pp. 439 - 470.
- Clough, G.W., Smith, E.M. and Sweeney, B.P., 1989. Movement control of excavation support systems by iterative design, *Proceedings ASCE Foundation Eng: Current Principles and Practices*, ASCE, pp. 869 - 884.
- Edwards, K.J. and Warren, W.P., 1985. The Quaternary studies in Ireland. In: K.J. Edwards and W.P. Warren (Editors), *The Quaternary History of Ireland*. Academic Press, London, pp. 1 - 16.
- Gaba, A.R., Simpson, B., Powrie, W. and Beadman, D.R., 2003. Embedded retaining walls - Guidance for economic design, *CIRIA Report No. C580*.
- Long, M., 2001. A database for retaining wall and ground movements due to deep excavations. *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, 127(3): 203 - 224.
- Long, M., Brangan, C., Menkiti, C., Looby, M. and Casey, P., 2012a. Retaining walls in Dublin Boulder Clay, Ireland. *Institution of Civil Engineers Journal of Geotechnical Engineering*, 165(GE4, August): 247 - 266.
- Long, M., Daynes, P.J., Donohue, S. and Looby, M., 2012b. Retaining wall behaviour in Dublin's fluvio-glacial gravel, Ireland. *Institution of Civil Engineers Journal of Geotechnical Engineering*, 165(GE5, October): 289 - 307.
- Long, M., Menkiti, C., Skipper, J., Brangan, C. and Looby, M., 2012c. Retaining wall behaviour in Dublin's estuarine deposits, Ireland. *Institution of Civil Engineers Journal of Geotechnical Engineering*, 165(GE6, December): 351 - 365.
- Long, M., Murphy, M., Roberts, T., Clancy, N. and Murphy, P., 2013. Deep excavations in water bearing gravels in Cork. *Quarterly Journal of Engineering Geology (QJEGH)* Paper submitted November 2012.
- Peck, R.B., Hanson, W.E. and Thorburn, T.H., 1974. *Foundation Engineering* 2nd Ed. John Wiley and Sons, New York.
- Stroud, M.A., 1988. The standard penetration test: its application and interpretation, *Proceedings ICE Conference on Penetration Testing in the UK*. Thomas Telford, London, University of Birmingham, pp. 29 - 51.