12th Aug 2016

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For the attention of **Mark Rushgrove**

Ref: 29 New End
Response to GMA queries

Dear Mark,

Please find enclosed our response to Campbell Reith's queries regarding the Ground Movement Assessment completed for the proposed 29 New End project. Specifically, these responses refer to the queries outlined in Paragraphs 4.7 and 4.8 of the Basement Impact Assessment Audit (revision D1).

Response to Para. 4.7:

Item 1: The building dimensions for New End Theatre, Lawn House, and Christ Church Cottage should be reviewed as smaller elements are more vulnerable to damage. New End Theatre appears to be closer to the edge of the excavation than assumed;

The length of the wall segments are subdivided by Xdisp into sub-lengths of approximately 1m. So it is considered that damage to shorter lengths are appropriately accounted for in the analyses.

The geometry of the neighbouring buildings have been reasonably simplified/idealised.

Very short wall segments, e.g. less than say 1m to 2m, are not considered to be well represented by the Burland method. In these cases it is considered that wall elements are unlikely to behave as an elastic beam subject to bending/shear mechanisms given the large wall height to length ratio.

The position of the buildings relative to the proposed excavation have been located based on the available ordnance survey data and geo-referenced location of the proposed substructure layout. It is assessed that the distance of the neighbouring structures to the proposed excavation is accurate as incorporated into the Xdisp analyses.

Item 2: It is understood that the outcomes of the Plaxis analysis were normalised against the excavation depth. It should be clarified what was assumed for H in figure 4.2 of the GMA report, as it is not the same for prediction curves for installation and excavation. Also, it should be confirmed what depth was assumed for retaining walls piles;

Normalisation of the finite element output was with regards to the retained height of the excavation. At Lawn House this height was taken as the difference between +118.8m AOD and +109.0m AOD. It is recognised that the curves for installation and excavation accept different height/wall length parameters. Though it is assessed that the ground movements due to installation effects are generally of second order compared to those due to excavation.

The embedment depth of the wall was assumed to be between approximately 4m and 5m, where the retained height was ranging between circa 9m to 11m.

It is recommended that the GMA is reviewed by the Engineer following finalisation of the detailed design of the embedded retaining wall elements.

Item 3: Justification for the assumptions made in the GMA regarding stiffness of cohesive strata is required with confirmation that the SPT N60 design profile represents a 'cautious' assessment;

Figure 1 provides a review of the SPT N_{60} results used to develop the adopted design profile. It is considered that the adopted design line presents a cautious assessment of the variation of SPT N_{60} with elevation, particularly with regards to the results within the retained height of the excavation. Notably, BH101 tended to indicate a lower trend, though it was considered to be an outlier for the assessment.

The drained Young's modulus of the cohesive Claygate Beds was assumed to be approximately 50 MPa at the surface (circa +102m AOD, approximately 17m below ground surface at the Lawn House section) and increasing at a rate of 2 MPa per meter. This was considered to be a conservative estimate of the stiffness of these beds, which makes an allowance for the anticipated level of strains in the retained ground mass in typical operating conditions.

The undrained shear strength of the clay may be approximated based on SPT blow counts as, $s_u = 5\ N_{60}$ (in kPa). A typical rigidity index for overconsolidated clays in London, which allows for small strain levels at working conditions behind the retaining wall is $E_u/s_u = 500$. The SPT N_{60} at the top of the beds is approximately $N_{60} = 30$ and increasing at a rate of approximately 1 N_{60} /m. Thus, based on the preceding discussion, the adopted drained stiffness profile is conservative and nominally 10 MPa less than what could be taken at face value from the available data. The adopted stiffness profile is considered to be cautious in this respect.

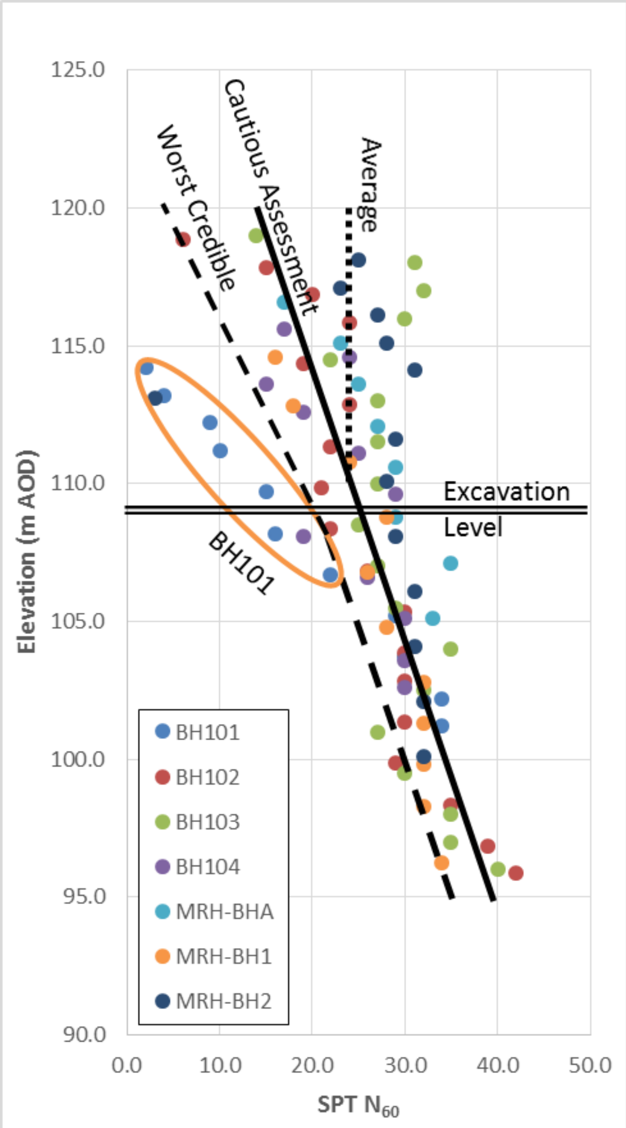

Figure 1: Select SPT-N60 profile

Item 4: It should be clarified what allowance has been made for ground movements during enabling works, i.e. grubbing out of foundations/ substructures and re-profiling of the site including temporary batters;

The GMA incorporates movements due to demolition of the existing Nurses Home and deformations due to reprofiling the existing ground surface to meet the proposed excavation sequence as part of the 2D FE modelling.

The GMA does not explicitly incorporate movements due to localised removal of obstructions or grubbing out of existing structures. The ground movements associated with such works are considered to be dependent on the methodology adopted to undertake the works and the level of workmanship involved.

Based on reviewing the Contractor's proposed Construction Sequence drawings, it is assessed that excavations to remove obstructions in sensitive areas (i.e. adjacent to Lawn House) will be shallow and will not intercept a 45° line extended from the underside of the existing building foundation level. In this respect, it would be anticipated the effects of localised excavations to remove obstructions would be small.

Notwithstanding, it is strongly recommended that the methodology adopted to remove obstructions is reviewed by the Engineer and Construction team at the time they [the obstructions] are identified to ensure that unacceptable ground movements do not result from the works.

Item 5: Temporary works drawings appear to show sheet pile walls to act as a cantilever (e.g. section A, stages 2A and 2B). It should be confirmed whether this has been incorporated into the assessment;

The sheet piling in the temporary phase has been incorporated as part of the FE assessment.

Given the estimated underside of the existing walls of Lawn House (circa +117.1m AOD – refer Engineer's Section D-D' in BIA), it is expected that the proposed temporary retention of the sheet pile walls will not lead to excessive ground deformations, as the foundation of the Lawn House are not expected to be significantly undermined. As an aside, it is noted that the foundation level of Lawn House has been conservatively assumed to be at +118.8m AOD in the finite element analyses, to provide additional degree of conservatism when assessing the ground movement due to temporary works.

It is recommended that the location of nearby temporary propping be considered again during detailed refinement of the construction sequence, such that the risk of ground movements associated with temporary works in critical areas can be mitigated. Additionally, consideration to carrying out hit-and-miss installation of working platforms, etc. could also be considered to reduce the risk of excessive ground movements occurring.

Item 6: It is noted that the proposed retaining walls in east-west direction, i.e. adjacent to Lawn House and Christ Church Cottage, are not retained by any structural element, and thus, form cantilever walls of up to 6.5m high. The GMA assumes excavation in front of a 'high-stiffness' wall which would require them to be propped at all times.

With regards to Christ Church Cottage, the foundation levels of this building are at approximately +115m AOD (refer Section A-A of Engineer's Building Foundation Sections in BIA). Thus, although the adjacent basement wall of the New End development will be topped-off at approximately +120m AOD, the top 5m of the wall will effectively be only retaining Christ Church foot path. In this respect it is considered that the cantilever at this location is less critical than that adjacent to Lawn House.

The 2D finite element model was used as a means to select the relevant Ciria curve. It is assessed that the deformation of the proposed retention system is generally enveloped by the Ciria curves, even though some portions of the permanent wall cantilever up to 6m.

In the short term the walls are propped with temporary propping at two levels. In the long term, the retaining walls are propped at basement level and ground floor for all walls. Approximately, the middle third of the northern retaining wall is also propped at the first floor level in the final condition.

It is noted that the locations where the wall is cantilevering the maximum distance are near to the return walls of the excavation. So it is assessed that the deflections predicted from the 2D analyses are probably higher than what may be expected in reality due to the 3D effects related to soil arching. Additionally, the ground level reduces significantly toward the south of the development, thus further reducing the potential for full plane strain conditions to develop.

Finally, the pile wall will be made integral with a thick internal lining as part of the permanent works build up (increasing total build up to approximately 1100mm in front of Lawn house). This wall will be heavily reinforced (not only due to the cantilever condition, but also for crack control reasons, etc.). This internal lining will also act to redistribute the loads around the structure through its ability to span bi-axially.

Notwithstanding the above, a simplified sensitivity check on the effect of adopting a "Low Stiffness" wall was assessed as part of the GMA for Lawn House. As shown in Figure 2, the maximum predicted Damage Category is Category 2 – Slight. This is within the existing maximum damage category assessed for Lawn House, albeit the position of the damage category coordinate is located further within the Slight damage contour interval.

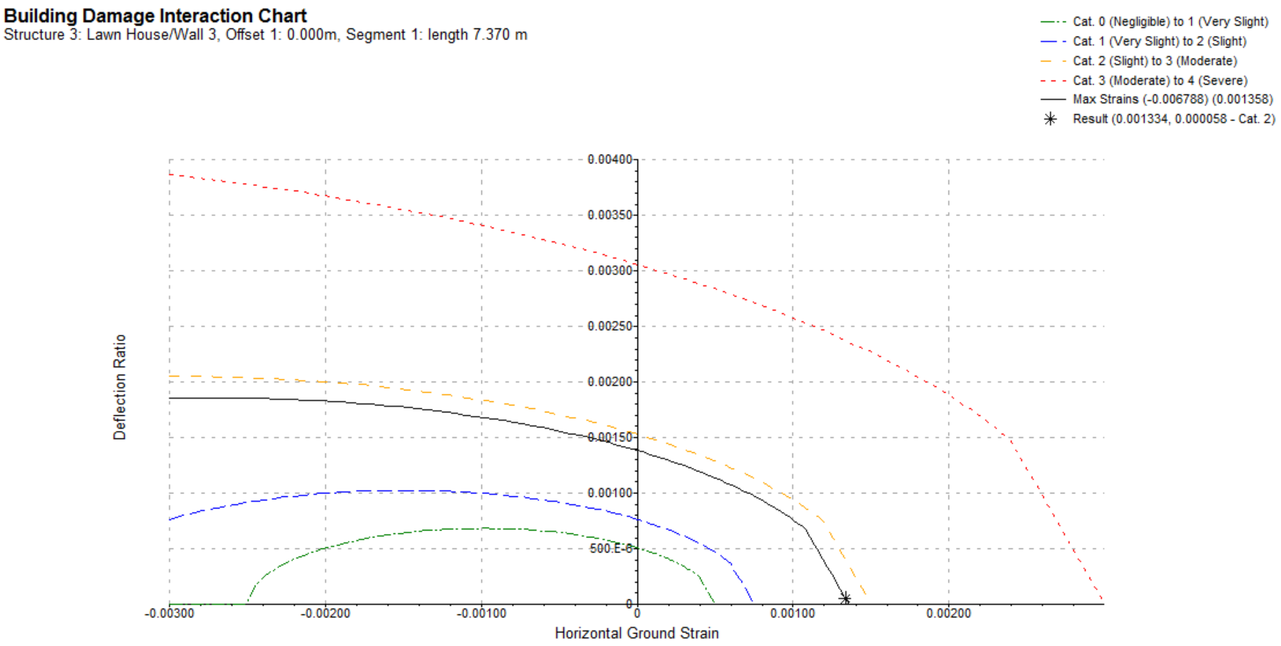

Figure 2: Damage category on the assumption of a "Low Stiffness Wall" at Lawn House.

Item 7: It is noted that the GMA uses the assumption of 'contiguous piled wall', whilst the proposed construction consists of 'secant' walls that are known to exhibit larger ground movements. It is not considered that this represents a 'cautious assessment'.

The adopted reduced installation effects were considered appropriate based on the proposed pile construction methodology, incorporating the use of full length temporary casing during pile construction to reduce ground movements.

This selection was partly informed based on a recent paper by Ball and Langdon (2014) that provides records of installation induced ground movement for cased CFA piles to retain a two-storey basement excavation in approximately 8m of made ground and terrace gravels. Based on their monitoring, they demonstrate that the maximum deflection ratios for installation can be limited to approximately 0.02%, which is approximately half of the maximum value quoted for contiguous pile walls in Ciria.

Additionally, it is evident from Ciria C580 that the estimated horizontal ground movements due to secant pile wall installation are primarily based on historical ground movement records obtained during the construction of the Bell Common excavation (circa 1982-1983). It is worthwhile noting that the Bell Common secant pile wall was:

- Constructed with the use of a bentonite support fluid (inferred from Gunn et al, 1992) to restrain the pile borehole. Temporary casing were not employed.
- Partly retained London Clay with a high coefficient of Earth Pressure in the order of 1.5 to 2.0 (Gunn et al, 1992).

It was assessed that these conditions, which form the basis of the horizontal ground movement predictions of secant pile walls in Ciria C580 were sufficiently different from what may be expected at the New End development site. On this basis it was assessed that the installation effects due to a contiguous pile wall may provide a more realistic estimate of installation induced ground movements.

Notwithstanding the above justification, sensitivity analyses were carried out to assess the damage category predicted at Lawn House if the full secant pile installation effects were adopted for the analyses. The sensitivity analyses indicate that the Damage Category for Lawn House (previously identified to be the most critical structure in terms of building damage category) remains within the predicted Category 2 – Slight range (Figure 2). Albeit, whereas previously the damage category identified in the GMA was estimated to be straddling the Category 1/Category 2 boundary, the damage coordinate is now centred within the Slight damage range. Nevertheless, there does not appear to be orders of magnitude differences in ground strain and thus building damage, due to the selection of a much more conservative pile installation effect.

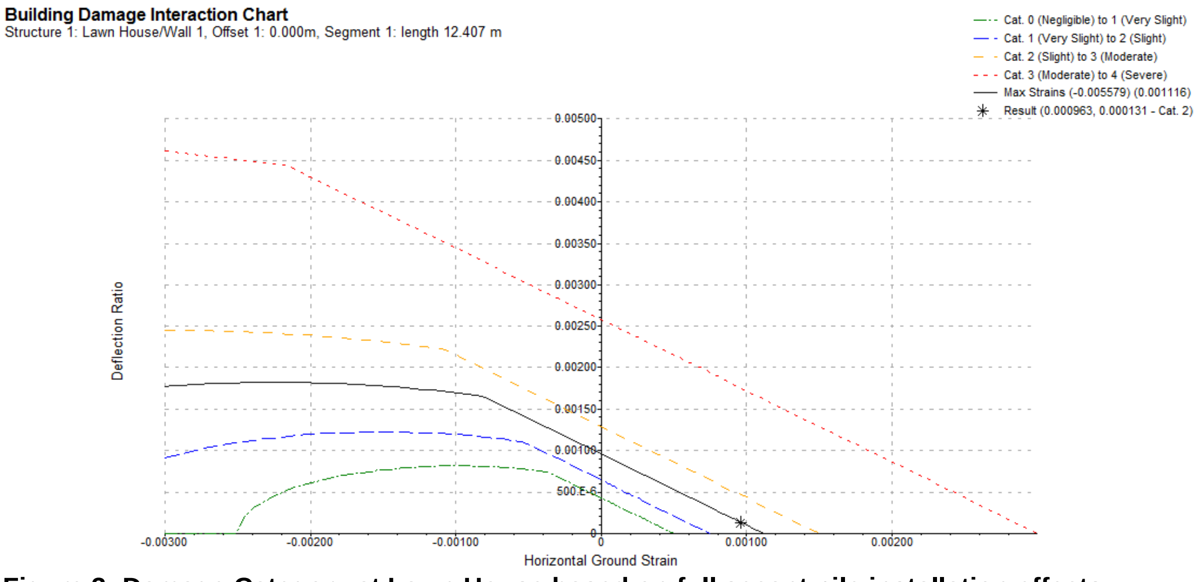

Figure 3: Damage Category at Lawn House based on full secant pile installation effects. Overall damage category does not change from existing GMA damage category.

Response to Para. 4.8:

Item 1: The methodology adopted in the GMA is queried by ABA. Subject to the resolution of the queries noted above, the approach taken is considered appropriate at this stage. However, it is recommended that the GMA is reviewed and, if necessary, revised to reflect the finally adopted construction methodology. At that stage, consideration should be given to importing the movements *predicted in the FE analysis for the damage assessment since the maximum movements in propped walls occur at depth.*

The methodology adopted for this GMA was to use the finite element method to justify the selection of a representative Ciria curves. This was considered to be suitable given some of the atypical features of the development site (i.e. asymmetric ground levels, sub-soils, etc.). Notwithstanding, it has been demonstrated that even employing significantly more conservative selections of wall stiffness or installation effect do not necessarily correlate with an overall increases in the predicted Damage Category.

The finite element results were not used directly in the assessment, because it was assessed that the adoption of a more simplified method of analysis based solely on Ciria data would provide improved transparency regarding how the estimated building damage categories were evaluated. It is recognised that additional finite element modelling may be required to satisfy various stakeholder requirements, particularly with regards to identifying the effects of out-of-plane actions, etc., which cannot be explicitly accounted for in the 2D method adopted to date.

It is acknowledged that there are varying avenues by which a GMA can be approached. We consider that the approach taken to date provides an appropriate level of analysis and site-specific consideration, which is commensurate with the scale of the proposed development. Additionally, we have aimed to tie together both analytical methods of analysis, with a database of empirical records of ground movement, to provide a robust assessment of potential ground movement.

References:

1. Ball, R., Langdon, N., 2014, *Prediction of party wall movements using Ciria report C580*, Ground Engineering.
2. Gunn, M.J., Satkunananthan, A., Clayton, C.R.I., 1992 *Finite element modelling of installation effects*, ICE conference on retaining structures, pp 46 – 55.

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