

Technical Note on the Excavation for a Domestic Property on Land Adjacent to 261 Graig Road, Godre Graig.

Introduction

Geotechnology Ltd has been asked by Mr H Jones, the owner of the plot of land adjacent to 261 Graig Road, to provide an excavation plan showing how the ground should be reprofiled to accommodate a series of proposed retaining walls. The walls have already been designed by others, so Geotechnology's instruction is limited to developing a plan for the ground reprofiling in advance of the wall construction. Whilst considering excavation sequencing, Geotechnology has determined that a very deep excavation is required and has become concerned that the slope stability needs to be verified.

Stability Analyses

The retaining walls have been designed by Mr Jones engineers and a set of calculations have been made available to Geotechnology. The calculations demonstrate internal wall stability but do not consider global stability of the wall/slope system: accordingly, though not part of the instruction, Geotechnology has carried out a series of limit equilibrium analyses to check global stability. Initially, Geotechnology used strength, density and geometry data from the retaining wall analyses and certain groundwater assumptions but the analysis revealed problems with the global stability of the wall/slope system.

Supplementary Investigation

Having determined that the wall/slope system did not have an adequate Overdesign Ratio with the assumed parameters a ground investigation was undertaken to derive site specific strength and groundwater parameters for the analysis. The analysis comprised a series of 5 dynamic probe profiles undertaken along the wall lines to develop strength/depth profiles. Four of the dynamic probe holes were fitted with groundwater piezometers to measure water pressures after enough time had elapsed to record equilibrium water levels.

Ground Investigation Data Analysis

The ground investigation data comprises a series of blow counts required to drive the standardised tip forward into the ground a distance of 75mm. The complete depth of the probe hole therefore comprises a continuous record of blow counts against depth at 75mm increments. As the "Standard Penetration Test N Value" is the sum of four consecutive 75mm increments the data has been compiled into profiles of running (overlapping) SPT "N" values. The figure attached to this report provides the continuous strength profiles for each Dynamic Probe, though the raw "N" values have been converted into the Angle of Shearing Resistance.

Deriving the Angle of Shearing Resistance from SPT "N" Values is permitted by Eurocode7 using correlation. The relationship between N Value and Friction Angle published by Dunham has been used after first normalising the N Values to N_{60} Values. Each "N" Value has been used to derive the equivalent friction angle in degrees and the Figure shows plots of this data. With the exception of Dynamic Probe 1 (which has been driven into the ground close adjacent to deep drains) the data is remarkably consistent. The data fits neatly into the following strength envelope:

Ground Level to 1.0 metre	26degrees
1.0 metre to 3.5 metres	40degrees
>3.5m	refusal (>40degrees)

The refusal of the probe-holes to be driven beyond 3.5m (with the exception of PH1 which was known to be in an anomalous area) indicates that very strong or very coarse ground is present at relatively shallow depth below existing ground level. The results could indicate a boulder rich layer, which would not be unusual in deposits of glacial origin or could be an indication of rockhead. If the refusal is a result of shallow bedrock, then the excavation will be considerably more difficult and would require the use of specialist rock excavation equipment. In this case stability would cease to be a significant issue unless unfavourable discontinuities are uncovered.

Groundwater Pressure

The piezometers installed into the Dynamic Probe Holes were measured after two weeks and the following water levels were recorded:

PH1	4.6m (dry)
PH2	1.95m
PH4	1.95m
PH5	2.44m

The measurements reveal high water levels in the piezometers; this is a strong indication that during excavation significant destabilising inflows of groundwater could be expected. The excavation contractor should be warned of the need to control groundwater pressures and flows during excavation. The design of the retaining walls should incorporate a robust groundwater drainage system behind the wall to ensure effective drainage over the full working life of the walls, and this is an underlying assumption of the stability analyses.

Limit Equilibrium Analyses

Having determined from Geotechnology's initial ground reprofiling models that the house is to be situated within a deep excavation, the architect's drawings were amended to show the relationship between existing ground profiles and the proposed retaining wall system. The revised drawings were produced in July 2018 and were a modification of the initial design: these "Revision B" drawings have been transcribed into the slope stability modelling. Further refinement of the design was made in March 2019 and these refined designs have been used as the geometry of the limit equilibrium analysis.

Stability modelling has been undertaken using Slide2018, a specialist limit equilibrium modelling package for the analysis of soil and rockslopes. The software requires the geometry of representative sections to be created, and this has been undertaken by choosing section CC (across slope) and Section AA (along slope) from the architects revised drawings. The three retaining wall positions have also been taken directly from these drawings.

Wall Construction

The retaining walls shown on the design drawings comprise two upper gravity walls retaining the garden and reducing site levels, and a reinforced concrete cantilever wall supporting the ground adjacent to the lower level. These have been modelled with the geometry shown on the drawings. However, limit equilibrium models are unsuitable to analyse retaining wall internal stability: accordingly, the walls have been assigned "infinite strength" as a device to

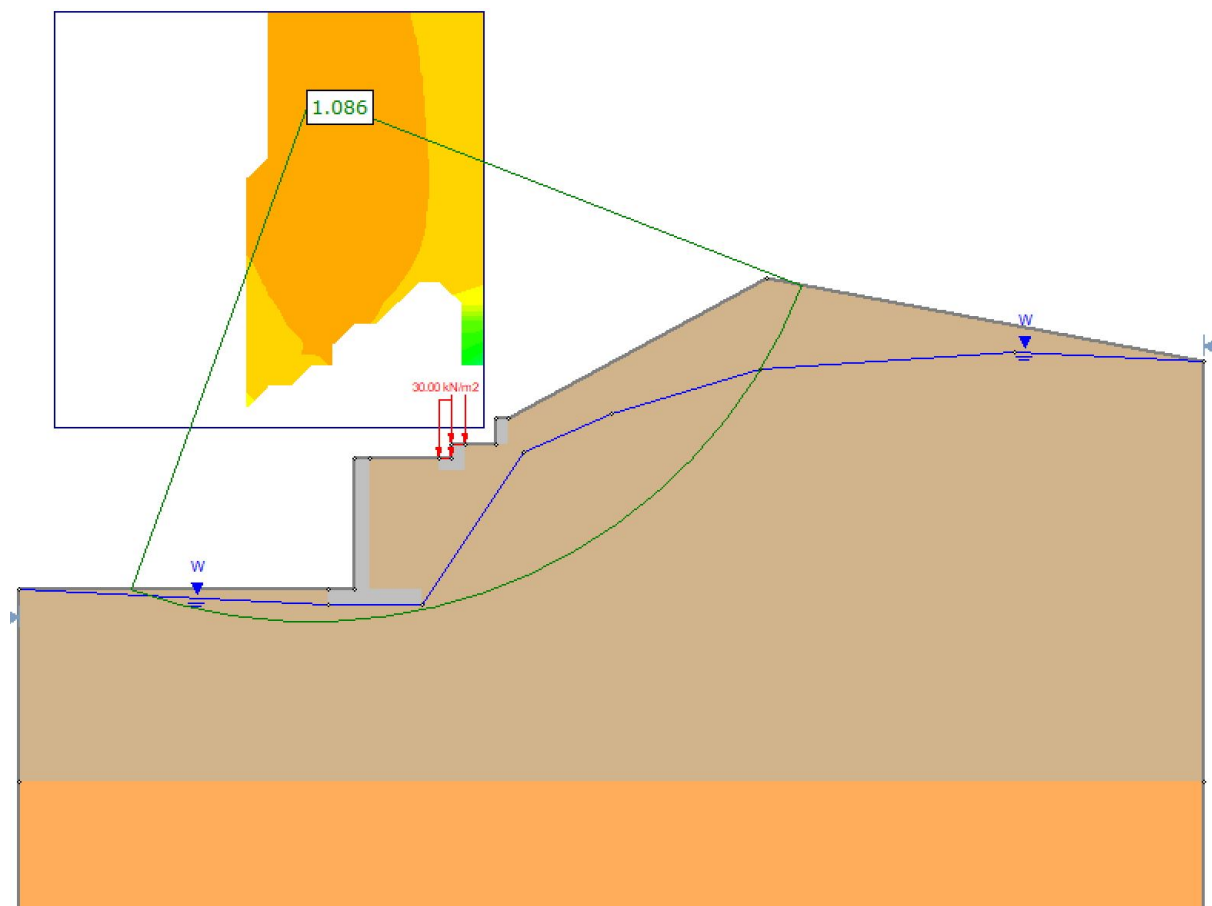
prevent failure surfaces developing through the vertical ground profile. This is a reasonable means to prevent the software creating implausible failure surfaces through the walls. The consequence of this is that trial surfaces will only be created beneath and between walls, a reasonable approach to the wall/soil system analysis.

Factor of Safety

It is convention to express the safety of a slope system as a single number, the Factor of Safety. The FoS is the ratio between those forces within the slope that are destabilising the slope and those that are resisting movement. Modern standards for design throughout the UK and Europe require that the ratio of capacity and demand is expressed after the input parameters have been adjusted by partial factoring. The analyses provided in this technical note use the EuroCode7 compliant overdesign ratio (ODR) to express the safety of the slope, with a numerical value exceeding 1.00 being acceptable and a numerical value less than 1.00 being unacceptable.

Analysis of Section CC

Several runs of the model have been carried out to determine the stability of a cross-section through the wall/slope system as it is illustrated on Revision C of the design drawings. Small adjustments to the slope above the retaining walls have been made, resulting in the stability model output shown below. This model indicates that the Overdesign Ratio exceeds 1.0 and therefore the Limit State GEO required by Eurocode7 is verified.

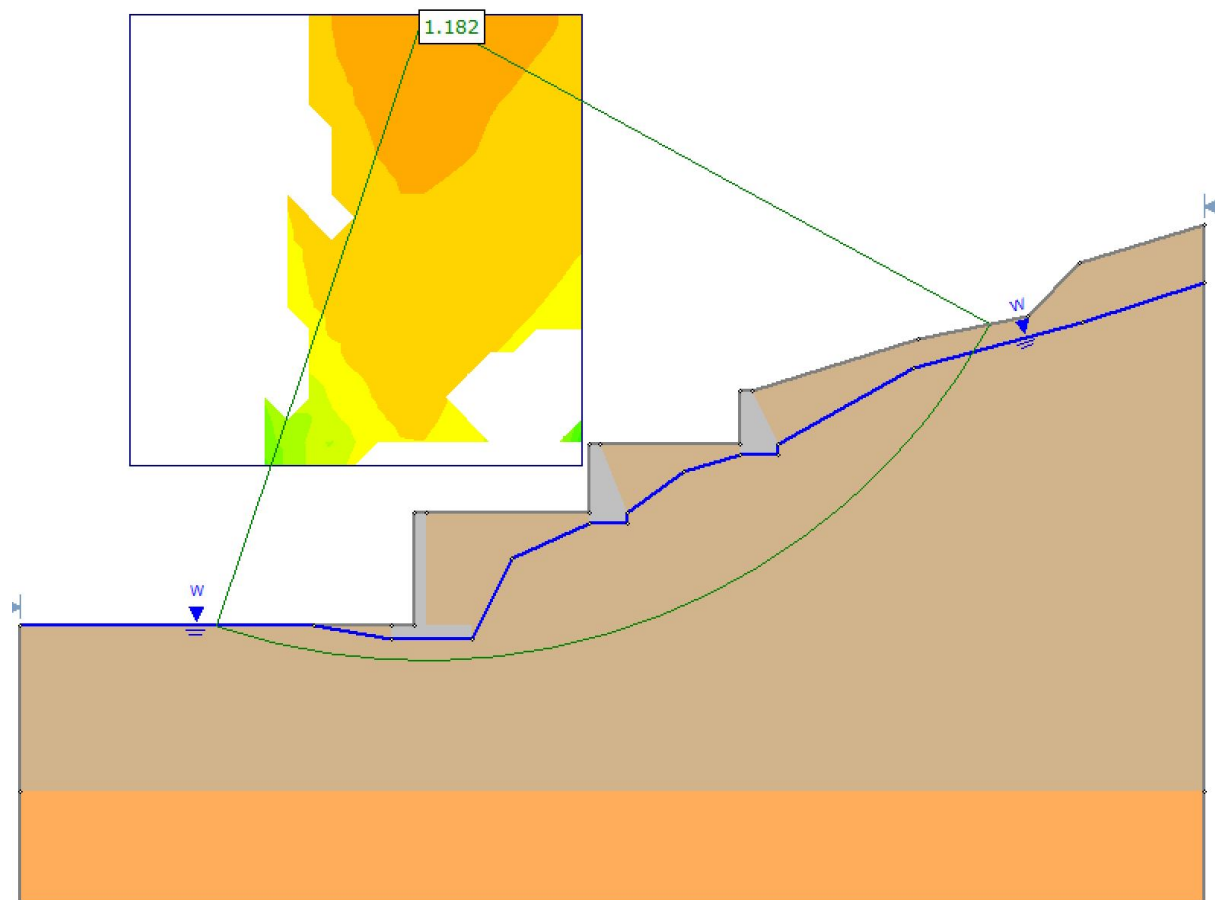


Stability Analysis Output for Section CC

It should be noted that the groundwater profile used in the analysis is not that revealed by the investigation; it has been assumed that the walls will have an effective drainage system and thus the groundwater will be drawn down to the levels shown. It should also be noted that an effective drainage blanket will be required beneath the floorslab as this too contributes to reducing groundwater pressures.

Analysis of Section AA

Section AA cuts longitudinally through the slope and includes the garden retaining walls. The garden walls have been modelled as gravity walls whilst the retaining wall for the rear of the property is a cantilever wall. The overdress ratio is acceptable when groundwater levels are maintained below wall levels underlining the importance of controlling groundwater levels in the long term. Drainage beneath the floorslab will also be required.



Stability Analysis for Section AA

Conclusions

A pair of limit equilibrium models have been run numerous times to evaluate the overall stability of the retaining wall/slope system and those factors that influence stability. It has been shown that the arrangements of walls shown on the design drawings has adequate stability when groundwater is controlled to levels at or below the levels shown on the model outputs. This will require careful detailing of the drainage behind and beneath the walls and floorslabs.

Implications for Retaining Wall Design

With the benefit of the ground investigation data the strength profile indicated above should be used for design, after being suitably factored so that the design complies with Eurocode7. Groundwater levels are naturally high and will have to be drawn down by drainage behind the wall. It could reasonably be expected that the wall drainage system will permanently collect water. Careful detailing to prevent clogging of the drainage media will be required.

Surface water from the slope above is currently piped through the construction area. Permanent drainage pipes will have to be carefully detailed and constructed to avoid leakage into the ground around the walls.

Excavation Plan

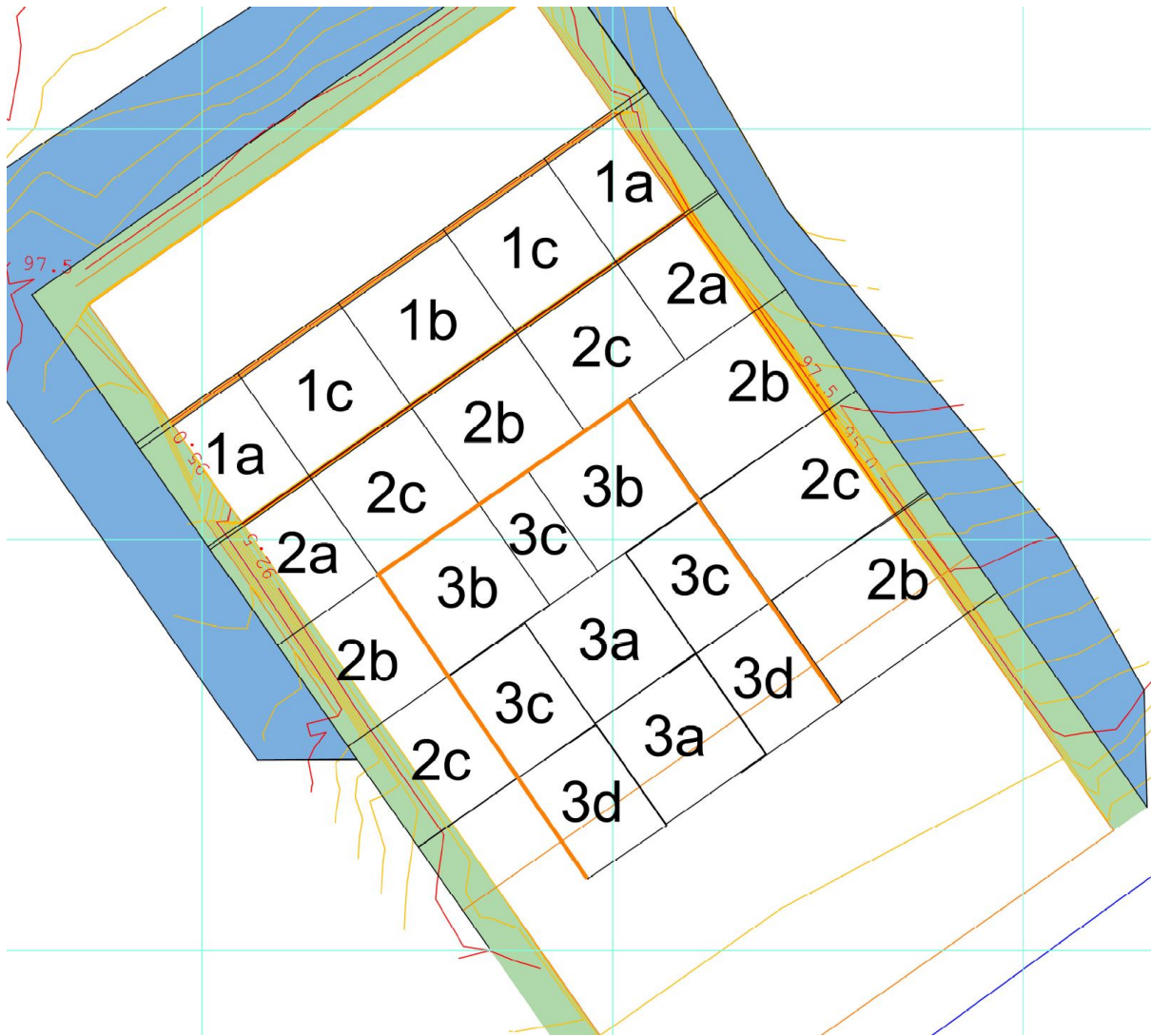
The analysis undertaken during this study has shown that if “wished in place” the retaining wall/slope system is stable in the long term. This depends upon groundwater levels being controlled to levels shown on the cross sections by effective drainage measures. It also depends upon the soils retaining their peak strengths, and to do so, the temporary works will have to be completed rapidly to avoid any movement of the soils during the construction period.

There is no rational means to estimate stand-up time for temporary works cuts, and therefore it has to be assumed that such cuts will need to be carried out rapidly before being supported with the retaining wall. To minimise the period of temporary works slopes, excavation should be made in a series of stages, with subsequent stages commencing when previous stages are supported.

The excavation of significant temporary slopes presents geotechnical risks to the development as well as safety risks to those carrying out the works. Accordingly, an experienced contractor should be engaged to undertake the principal excavation in a safe and effective manner. A preliminary designers risk register has been developed and is appended to this report: this must be communicated to the contractor so that appropriate planning can take place to control risks from the works. The contractor should excavate slopes and construct groundwater drainage as well as the retaining walls.

Excavation Sequencing

The ground reprofiling should be undertaken in a top-down staged sequence. Firstly, the upper of the two garden walls should be constructed by making preliminary cuts into the wall corners, as shown as Stage 1a on the excavation sequence drawing. The corners are the strongest part of the wall and also retain the most stable part of the ground due to the arching effect on the corner of the excavation. After the corners have been constructed along with 2.5m of wall, the soil buttress left between the wall corners can be removed to construct the wall (1b and then 1c). Careful detailing on the joints should be specified by the structural engineers. The side walls can be constructed lastly to complete the upper wall. This is routine work and can be carried out by general building contractors.



Excavation Sequence Plan

With the upper wall completed excavation for the corners of the middle wall can be commenced, following the same staged sequence as the upper wall, as shown as Stage 2a on the excavation sequence drawing. After the corners have been constructed along with 2.5m of wall, the soil buttress left between the wall corners can be removed to construct the wall as Stages 2b and 2c. Careful detailing on the joints should be specified by the structural engineers. The side walls can be constructed lastly to complete the middle wall. This too is routine work and can be carried out by general building contractors.

Reprofiling of the eastern slope should be undertaken at this stage. The middle wall should be extended into the short upper slope retaining wall. As this is constructed counterfort drains can be placed into the upper slope. Some localised small walls and landscaping of the upper slope should be made at this stage. Specialist drainage work may be required, depending upon groundwater levels encountered during the works.

The excavation of the upper and middle retaining walls (and the upper slope retaining wall) will produce a significant quantity of soil arisings which will need to be cleared from the site prior to the next construction stage. Arisings should be progressively cast toward the front of the site where trucks will be loaded.

The lower retaining wall will have to be cast in sections as the ground will react adversely to the excavation of the entire wall profile. A bulk dig should be made first to remove the soil mass from the centre of the footprint, as shown on the excavation sequence drawing (3a). Then, the corners of the wall should be cut first, following the same staged sequence as the upper and middle walls (3b). After the corners have been constructed along with 2.5m of wall, the soil buttress left between the wall corners can be removed to construct the wall (3c). Careful detailing on the joints should be specified by the structural engineers. The side walls can be constructed lastly (3d) to complete the lower wall.

During the excavation of the main wall a significant temporary slope will be formed. The eastern cut will abut the toe of the newly profiled slope whilst the western cut will be very close to adjacent properties. The staged construction will avoid large exposed faces and will support the temporary cuts, but the ground must be supported quickly. A compounding influence will be the ingress of groundwater, a destabilising influence. Cutting the slopes at the end of the summer will ensure groundwater levels are as low as possible but the potential for problematic quantities of groundwater should not be overlooked.

The proximity of the lower cuts to boundaries, their location beneath slopes and other retaining walls and the requirement to control groundwater inflows indicates that this work should be undertaken by a specialist contractor.

Other Considerations

The prospect of striking rock or a very hard stratum to the rear of the property cannot be ruled out. Excavation into this stratum may prove challenging and the possibility of bringing the rear retaining wall forward to avoid difficult excavation conditions should be considered. Such design is best undertaken prior to rather than during the works and accordingly it would be of benefit when garden wall excavation commences to excavate a trial pit to examine the ease of excavation.

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Designers Geotechnical and Safety Risk Register

- P1 **Steeply sloping natural ground surface**
Increases risk of trips, slips and Falls
- P2 **Steep Temporary Cut slopes required for Retaining Wall Construction**
Excavations must be guarded to prevent fall from above
Toe of cut must be avoided by site staff unless slope is confirmed to be stable
- P3 **Significant trees Could be Undermined during works**
Ground excavation downslope of trees could result in falls
- P4 **Surface Water flooding from Hillside Drainage**
Existing drainage should be confirmed to be effective for temporary and permanent works
- P5 **Extremely slippery ground when Wet**
Increases risk of trip, slips and falls
- P6 **Cut Slopes Too Steep for permanent slopes**
Short term standup time requires prompt work and should minimise open cut duration to reduce risk of localised slope movement
- P7 **Large Cobbles and Boulders will be exposed in Cut Slopes**
Large particles could fall out of slope and fall into excavation below
- P8 **Groundwater Inflows Could be large and destabilising.**
Temporary works groundwater control measures must be available to react to level of inflows
- P9 **Ineffective drainage Could Cause Long Term Strength Reduction**
Groundwater drainage needs to be effective over long term to control groundwater levels to those shown on the stability sections.
- P10 **Rock excavation could be required**
If rock is struck then rock breakers may be required. This should lead to structural surveys of adjacent properties and walls and may require vibration monitoring.
- P11 **Temporary support to boundaries may be required**
In places the cuts approach close to boundaries which may need to be temporarily supported.