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# Automation in geotechnical design – application and case studies

## Automatisation de la conception géotechnique - applications et études de cas

Z. Farook
*Oasys, London, United Kingdom*

C. Matthews
*Oasys, Newcastle, United Kingdom*

M. Skinner, M. Brown
*Arup, Bristol, United Kingdom*

**ABSTRACT:** Automation – the use of computers to repeat tasks – is becoming increasingly important in engineering. The application of automation can provide technical and commercial benefits to an engineering design project: Costs and calculation time can be reduced, while the designs produced can be more efficient.

This paper presents two examples showing how Engineers have applied automation to geotechnical designs, writing programming code to make use of the COM (Component Object Model) interface embedded in commercial software. The first example shows a large site with the requirement to terrace buildings into a hillside with multiple retaining walls with different dimensions. The second describes how the design of bored pile and mini-pile foundations for railway overhead electrification was automated. The processes required and benefits of the method are discussed, as well as potential difficulties arising from the application of automation. The paper concludes with a brief discussion on the future potential of automation in geotechnical design.

**RÉSUMÉ:** L'automatisation – c’est-à-dire l'utilisation d'ordinateurs pour la répétition de tâches - devient de plus en plus importante en ingénierie. L'application de procédés d'automatisation peut apporter des avantages techniques et commerciaux à la conception de projets d’ingénierie : les coûts et le temps de calcul peuvent être réduits, tandis que les conceptions produites peuvent être plus performantes.

Cet article présente deux exemples illustrant comment des ingénieurs ont appliqué l’automatisation aux conceptions géotechniques, et ce grâce à l’écriture de code de programmation dans le but d’utiliser avantageusement l’interface COM (Component Object Model) intégrée dans un logiciel commercial. Le premier exemple présente un grand site sur lequel le projet est de construire des bâtiments, avec un terrassement en étage dans la colline et plusieurs murs de soutènement dont les dimensions varies. Le second décrit comment la conception de fondations sur pieux forés et sur mini-pieux pour les pylônes des lignes aériennes de contact a été automatisée. Les processus requis et les avantages de la méthode sont discutés, ainsi que les difficultés potentielles découlant de l'application de l'automatisation. L’article se conclut avec une brève discussion sur le potentiel futur de l’automatisation dans la conception géotechnique.

**Keywords:** Automation; Geotechnics, COM interface; Design; Oasys

# 1 INTRODUCTION

This paper discusses automation within geotechnical design, primarily through the presentation of examples of how automation has benefited the design and construction of two different civil engineering projects. It discusses some of the advantages and disadvantages of automation encountered on these projects, and goes on to discuss briefly the future of automation in geotechnical design.

In the examples, the focus of this paper is the automation of the geotechnical design method rather than the method itself; the latter is therefore not discussed except where relevant to the automation.

Several pieces of software are mentioned in this paper: Oasys Greta and Alp are commercially available software packages for the analysis of gravity retaining structures and laterally loaded piles respectively. PIGLET (Randolph, 2004) is a commercially available spreadsheet based tool for the analysis of pile groups.

# 2 PROJECT EXAMPLES

This section details the application of the COM interface within two different software packages to geotechnical designs for two construction projects in the UK. These examples are thought to be amongst the first in which automation has been applied to geotechnical design using these programs in this way.

The Oasys Greta and Alp software development team has added a COM (Component Object Modelling) interface to most of the geotechnical software within their suite. This enables Engineers to create data objects in common scripting languages (for example, VBA, Python, MATLAB) which allow program input and output to be shared between software and other software packages. The implementation of the COM interface effectively opens up the software packages to be manipulated programmatically; this in turn allows the calculations performed by the software to be built in to larger automation workflows.

The examples in the following sections illustrate how this was achieved on two projects.

## *2.1 Example – retaining walls*

### *2.1.1 Background*

Development of a steeply sloping site on the south coast of the UK required the design of a large number of cast in-situ concrete gravity L-section retaining structures of varying retained height, applied loading and foundation geology to accommodate the extensive terracing proposed. A method of automating this process was developed to save design time and to provide efficiency in the final solution. This method exploited the COM interface within Oasys Greta.

### *2.1.2 Automation topology*

The design inputs were collated in a Microsoft Excel spreadsheet. This spreadsheet was then linked to Oasys Greta via a VBA module which called the COM interface. The VBA module pushed the required inputs to Oasys Greta which then ran the calculation and returned the results via the COM interface to the workbook (see Figure 1).

The wall geometry (in this case, the wall base length) could be varied to optimise the resultant factor of safety on applicable failure mechanisms. This process was then repeated for each different combination of retained height, loading and geology. In each case, the VBA code incremented the base length of the L-section wall to find the minimum base length giving acceptable factors of safety on sliding, overturning and bearing capacity.

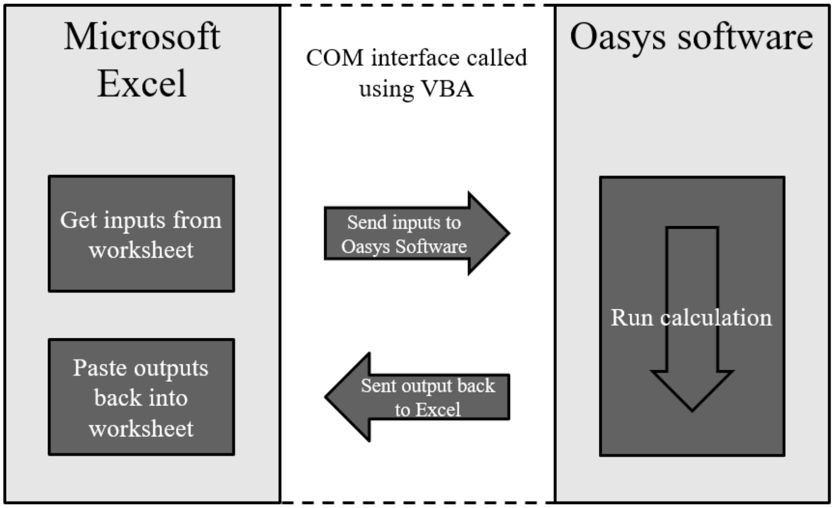

*Figure 1. Concept of linking Oasys Greta and Alp to Microsoft Excel using the COM interface (From Farook, Brown, & Skinner, 2017)*

#### *2.1.3 Output*

The overall result of the automated method was an autonomously optimised retaining wall solution for any number of situations for the site in question. The automation process represented both an efficient use of office based design time, but also of the use of raw materials, temporary excavations, and backfill volumes on site.

A database of design results was developed as the automated design process was run. This enabled rapid assessment of the required wall geometry for any intermediate retained height (i.e. between previously completed cases).

This database of retaining wall options was subsequently called on during production of the site-wide 3D model and detailing of each wall as refinements were made and details considered. For example, proposed site levels changed as building geometry and service alignments were finalised. Despite this, additional retaining wall design was not necessary, as the database provided bounding cases from which adjustments could be made.

### *2.2 Example – piled foundations*

#### *2.2.1 Background*

This example describes the application of automation to the design process for single bored piles and mini-pile group foundations on a railway electrification project. As part of the electrification of a railway line, Overhead Line Equipment (OLE) is installed along the route. The overhead wires are carried by support structures which are typically around 50m apart along the length of line. On this project, approximately 1000 foundations were required.

Several types of support structure are commonly used, ranging from single mast cantilever structures requiring one foundation to large gantries spanning several lines and requiring four foundations. On this project the structural Engineers typically defined more than 100 six degree of freedom foundation load cases per foundation.

The design loads for different types of structures are different, and clearly changes in ground conditions would be expected along a linear infrastructure site. Whilst some degree of rationalisation of foundation loading and ground conditions for OLE structures is possible, the sheer number of structures results in a significant foundation design effort.

Driven piles are commonly used to support OLE structures as they are relatively simple to install; on this project approximately 60% of foundations were driven piles. In some cases however they are not suitable, for example in station areas (where installation may damage buildings or services or where there is insufficient headroom), or where ground conditions prevent their use. In these areas, either single bored piles or groups of between three and six mini-piles commonly provide alternative foundation options.

Approximately 260 single bored pile foundations and 60 mini-pile group foundations were designed for this project. Several iterations of design were typically undertaken for each foundation to account for optimisation of the OLE or structural designs (resulting in revision to loads). Allowing for three designs per foundation we approach 1000 design calculations, each containing multiple load cases.

On this project, bored piles were generally 1000mm diameter reinforced concrete. Mini-piles were generally 320mm diameter, reinforced with a single central 40mm reinforcement bar and designed with a pin connection to the pile cap.

Note that for each structure designed, foundation design loads and ground conditions were defined in advance. For mini-piles, the pile caps were designed separately. These aspects are therefore not part of the automated method described in this example.

Every structure designed using the automated method was independently checked by a separate design team.

### 2.2.2 *Automated design of a single bored pile*

Oasys Alp models were first created for each ground model under consideration. These starter models, called “base models“, contained the ground model and associated soil parameters, the sectional properties of the pile, and appropriate design factor-sets.

As with the retaining wall method defined in the first example, inputs were then collated inside a control spreadsheet. This spreadsheet contained the ground model and associated soil parameters, the loads as defined by the structural Engineers, and any specified parameters required for the design.

The calculation method consisted of two main components. The first, lateral analysis, was completed by controlling Oasys Alp via the COM interface. For each load case defined the appropriate Alp base model was opened and the loads were pushed in to the model. Starting with a very short pile, the pile length was then increased in 200mm increments. For each increment the lateral displacement at the mast head was assessed, considering both foundation displacement and rotation. When the mast displacement under the applied load reduced to less than a pre-defined limit, the iteration would stop. This control iteration loop is shown simplified in Figure 1. For each partial factor set under consideration the Alp model containing the valid design was saved to an output folder for future reference.

The second component of the method was axial pile capacity. This was completed inside the control spreadsheet using routine methods, again for each load case defined by the structural Engineers.

The design pile length was the longest length of any of the calculation components, for any partial factor case.

### 2.2.3 *Automated design of a mini-pile group*

The automation of mini-pile group design was implemented by coupling Oasys Alp with the pile group analysis tool PIGLET (Randolph, 2004). As with the retaining wall and bored pile methods, a control spreadsheet was created that contained inputs, collated outputs, and undertook axial pile capacity calculations.

The first stage of the calculation was a calibration exercise. PIGLET models a single soil layer specified by a linearly changing shear modulus, with the user specifying a value at ground level and then a gradient with depth. A calibration was therefore undertaken between Alp and PIGLET to permit the representation of the multi-layered ground model with this linear parameter.

As with the single bored pile design, Alp “base models“ were created for each partial factor set, for each ground model. These base models modelled a single mini-pile. The control spreadsheet selected the appropriate base model, and for each partial factor case for each load case applied the resultant horizontal force and moment to the pile. Starting with a very long pile, the length of the pile was then reduced until the pile stopped acting as a long flexible pile. This situation was detected by checking the rotation and displacement of the base of the pile; when the base of the pile rotates and/or displaces, the pile was considered too short. The longest length of any case was then taken forward for PIGLET calibration. The bending moment and displacement profiles of the calibration cases (for each partial factor set) were extracted from Alp into the control spreadsheet using the available COM interface commands.

A series of PIGLET calibration models were then created. This was achieved by controlling the PIGLET spreadsheet from the control spreadsheet using VBA. A very large pile cap was defined so that no interaction occurred between piles. Calibration loads corresponding to the Alp models were then pushed into the PIGLET models.

Within each model an iteration was then started, where the shear modulus gradient was increased in small steps, starting with a very low value. This initial low value typically results in large displacements and small bending moments under the applied load. Note that the surface shear modulus was usually a small, constant value; this was a controllable input to the automation but was not varied as part of the calibration.

With each iteration the calculated bending moment and displacement profiles of the pile were extracted back into the control spreadsheet and superimposed on the Alp outputs. The difference between the pairs of curves was measured at eight defined depths. The difference reduced as the iteration proceeded, and when the difference then started to increase, a point of inflection had been reached. At this point the previous increment was taken as the calibrated gradient of shear modulus for use in the calculation. The matched bending moment and displacement profiles were plotted as graphs in the control spreadsheet to facilitate inspection of this process.

Having calibrated the shear modulus gradient, the second stage of the calculation was to analyse every load combination in PIGLET using the design pile configuration. Again, this was achieved by controlling PIGLET from the control spreadsheet. For each load combination and partial factor set a PIGLET model was created and run using the corresponding calibrated shear modulus gradient. The maximum resultant bending moment and displacement of any pile in the group was extracted into the control spreadsheet, along with the maximum and minimum axial load on any pile in the group. The recording of both maximum and minimum axial load permitted the capturing of any cases where piles were in tension. In addition to the pile results, the displacement and rotation of the pile cap was also extracted into the control spreadsheet. These results were combined to calculate the deflection of the mast head.

The third stage of calculation was the completion of axial pile capacity calculations. As with the single bored pile method, this stage was completed inside the control spreadsheet using routine methods. The calculation considered both compression and tension results.

Pile length was then selected as the longest pile required for any axial or tension case, or as calculated in stage one.

### *2.2.4 Outputs*

The control spreadsheets for both the bored pile and mini-pile methods produced two main outputs. A pdf summary output presented the key inputs to the design, the calibration (mini-piles only), and the results.

Alp and PIGLET models created for each load case and factor set combination were saved to an output folder next to the control spreadsheet. A log file was also saved into the output folder, providing additional detail on the calculations completed.

The date and time that the calculation was completed was stamped into the pdf summary, the output folder name and the log file.

## 3 BENEFITS AND DRAWBACKS

### *3.1 Benefits*

It is clear that there is significant potential for time saving by the automation of design calculations. As an example, the completion of one iteration of a mini-pile design “manually“ (i.e. without automation) on the railway electrification project typically took an Engineer one day. The manual calculation also required the use of enveloped load cases. The equivalent automated calculation, considering over 100 individual load cases separately, usually took 30 minutes to set up and complete. Very crudely comparing for the 60 foundations designed, this is 60 Engineer days for the manual method (assuming 1 day per foundation), versus four Engineer days for the automated method. Multiplying this time difference to account for design iterations quickly results in a significant design time (and hence cost) saving. Note that the initial time invested in programming the automated methods must be considered when deciding to automate, however the time saving is clearly of particular significance when there are a large number of analyses to be undertaken.

With automation the number of calculations it is possible to do becomes effectively independent of the Engineer‘s time. Extensive sensitivity and parametric analyses become possible, and the investigation of large numbers of calculation cases become not only possible, but quick and simple.

The removal of the need to use enveloped load cases or generic design scenarios provides efficiency savings in construction material costs. Limited comparisons for mini-piles on the railway electrification project showed that a reduction in pile length of 0.5 to 1m was possible. Whilst this is a small cost with respect to an individual pile, across a project this saving could become important.

In a similar manner, with the assessment of many combinations of actions or inputs it becomes feasible to undertake sensitivity analyses. This in turn permits the assessment of risk with respect to uncertainty in geotechnical properties. Having made this assessment, it may be possible to more effectively target design effort to reduce the risk.

Another benefit of automation is that calculations can be quickly adjusted or repeated in the event of changes to inputs (loads or site geometry for example) without significant time input from the Engineer. This was particularly valuable for the railway electrification project, as changing the configuration of one structure would often have a knock-on effect on the loading of adjacent structures. This is because they are connected by the overhead cabling.

The methods of automation discussed above demonstrate that automation is fairly straightforward, and requires access only to the software itself, Microsoft Excel, and PIGLET or a similar pile group analysis tool. Engineers with modest experience of VBA will become quickly familiar with the general process of using the COM interface. In contrast to setting up calculations from scratch entirely within Excel, there is a reduced scope for errors as the Oasys Alp and Greta software packages have gone through rigorous verification.

### *3.2 Drawbacks*

There is evidently a cost associated with setting up automation, and whilst templates and calculation methods can be re-used, there are often site specific requirements which must be accounted for. It may therefore prove unviable to set up automation where only small numbers of calculations or load cases are required.

There is sometimes a temptation with automation to believe that the solutions produced by the computer are somehow more correct than individually produced calculations and models, as so many cases have been analysed. By extension, a reduced amount of checking and reviewing could potentially and incorrectly be justified. In reality, this is not the case, and there remains a critical role for suitably experienced Engineers in ascertaining that the calculation output is sensible and reasonable. Whilst it is possible to check more load cases for example, this may in reality only mean that the same errors are repeated a greater number of times.

One drawback of using programming in calculations is that it can be more difficult to check the code than it is to check calculations that have been presented step-by-step. To mitigate this drawback, the authors recommend that:

i) Case study calculations are completed manually and used to validate the automation.
ii) The automated method presents sufficient results to allow Engineers to detect errors.
iii) The automation method is documented in detail, so that it can be understood and interrogated by other Engineers in the future, especially if the automation is reused.

## 4 FUTURE POTENTIAL

### *4.1 Engineers or developers?*

In the authors' experience, the use of automation by geotechnical Engineers on projects typically starts organically, with Engineers applying small components of automation to undertake specific (often repetitive or iterative) tasks more efficiently, or to enable them to test more cases. This type of programming is easily achieved using environments like VBA, MATLAB and Python; none of which require the compiling and creation of executable files. In this way Engineers deploy their individual programming skills and techniques, with the result that automation methods tend to be bespoke to the project and Engineer.

Code created by Engineers in the manner described above is likely to be fairly inefficient compared to what could be achieved by a software developer, however it is also likely to be much cheaper. With increasing complexity it is likely that software developers will have increased input into the application of automation to engineering projects, to make the methods more efficient and robust. Engineers do however have an advantage over developers in that they understand the method being programmed; this understanding is vital. A likely future trend is therefore that developers and Engineers will work more closely together.

### *4.2 Modular automation*

Linking together smaller automation components results in more powerful processes; this can be seen in the transition from designing single bored piles to mini-pile groups described in this paper. Regardless of the scale of the automation or project, the use of a modular automation structure is more likely to result in an automation process that can be adapted for the specific needs of future projects. The use of Python in particular supports a modular automation structure, and is especially powerful in terms of storing and calling specific automation components via a central repository. Python programmers also have access to a larger range of Application Programming Interfaces than VBA programmers, for example, increasing the scope of their automation.

### *4.3 Interdisciplinary automation*

The natural successor to the development of automation tasks for geotechnical design is the linking of automated components across engineering disciplines. As an example in relation to the railway electrification project discussed in this paper, the structural Engineers already use parametric software to assess the structural design. By linking the automated foundation design methods to this parametric software it would be possible to greatly reduce the number of design iterations. Similarly, it would be possible for the reinforcement design of piles to be linked to the geotechnical design, again reducing iteration requirements.

### *4.4 Design on demand*

It is understood, especially with respect to geotechnical design, that the situation on site during construction can vary from that adopted for design. When this occurs, it is often necessary to delay construction while the design is modified to incorporate the information from site.

With an automated method, the validation or adaptation of designs on demand during construction becomes more feasible, with timeframes greatly reduced. The requirements of quality assurance processes must however be adhered to in these situations.

The concept of design on demand is also applicable when considering the use of back analysis, used for example in the application of the Observational Method. This method is now specified in Geotechnical Design in CIRIA C760. Gaba et al. (2017) gives guidance on how the method can be applied to retaining walls and the application of this method requires automation. As part of ongoing research, the method has been applied to Oasys Frew for the design of flexible embedded retaining structures. Using the multi-variable stochastic analysis, each parameter in the retaining wall analysis is systematically varied and its effect on certain output, such as wall deflection, is quantified.

With advances in instrumentation and automation, the use of this method could lead to clear benefits in terms of economy and programme.

## 5 CONCLUSIONS

The examples presented show that the application of automation in geotechnical design is already providing technical and commercial benefits on projects. The use of the COM interface embedded in commercially available software such as Oasys Greta and Alp facilitated the application of automation on these projects. Developments being implemented in the geotechnical software suites, together with advancements in computing methods and design codes will allow Engineers to apply these methods to more projects in the future.

The fundamental question when considering applying automation in design remains whether the development time and cost will be recovered by the efficiencies gained. On the project examples presented this was clearly the case, but this question should be assessed each time automation is considered. The potential for re-use on other projects should be factored into this assessment.

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