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The investigation of the use of automation in dike and embankment projects

L'étude de l'utilisation de l'automatisation dans les projets de digues et de remblais

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ABSTRACT: Geotechnical projects have to be executed within available time and budget, which are limited. Presently, common project tasks are time consuming, require a lot of manual effort, are heavily repetitive and are prone to human errors. Automation might prove to be a solution for engineers. Automated workflows are time saving, more efficient and accurate, and can be implemented by means of scripts and tools. At Fugro, automation was applied during various stages of dike and embankment projects. In general, automating a workflow led to many benefits. For stability calculations, a significant gain in time efficiency was achieved as automated calculations led to a decrease of calculation times from three months to one day. Additionally, the analyses of soil investigation techniques were improved by new tools, effectively leading to a redundancy of repetitive tasks. Overall, automation led to increased work satisfaction, optimized design solutions and reduced processing times. This has led to safer, more cost efficient and sustainable geotechnical structures.

RÉSUMÉ : Les projets géotechniques doivent être exécutés dans le temps et le budget disponibles, qui sont limités. À l'heure actuelle, les tâches courantes d'un projet prennent du temps, exigent beaucoup d'efforts manuels, sont très répétitives et sont sujettes à des erreurs humaines. L'automatisation pourrait s'avérer être une solution pour les ingénieurs. Les flux de travail automatisés permettent de gagner du temps, sont plus efficaces et plus précis, et peuvent être mis en œuvre au moyen de scripts et d'outils. Chez Fugro, l'automatisation a été appliquée à différentes étapes des projets de digues et de remblais. En général, l'automatisation d'un flux de travail a entraîné de nombreux avantages. Pour les calculs de stabilité, un gain de temps significatif a été réalisé, les calculs automatisés ayant permis de réduire les temps de calcul de trois mois à un jour. De plus, les analyses des techniques d'investigation des sols ont été améliorées par les nouveaux outils, ce qui a conduit à une redondance des tâches répétitives. Dans l'ensemble, l'automatisation a permis d'accroître la satisfaction au travail, d'optimiser les solutions de conception et de réduire les délais de traitement. Cela a conduit à des structures géotechniques plus sûres, plus rentables et plus durables.

KEYWORDS: automation, algorithm, dike and embankment, stability, Python.

1 INTRODUCTION

Automation is the process of eliminating human tasks. It has become increasingly important in society (Helbing 2015), following the widespread automation efforts in the scientific community (King et al. 2009). The benefits of automation are, among others, the significant decrease of the human error factor and increase in time efficiency (Kaber et al. 2007). There are drawbacks with automation as well. A case study by Oke et al. (2017) shows that automation efforts in the construction industry has led to higher levels of maintenance and capital expenditures, as well as employee dissatisfaction and lower degrees of flexibility.

Geotechnical engineering has been subject to automation for the past decades (Wang et al. 2014). Automation in geotechnical engineering generally means the reduction of repetitive tasks. A typical automated workflow in a project reduces work, such as finding the right information for a parameter analysis, creating cross-sections of a geotechnical structure, updating calculations with new data, conducting sensitivity analyses etc. With these efficient and effective algorithms in place, only tasks such as algorithm output and data quality control, project planning and project consultation remain part of the responsibilities of the engineer. The general result due to automation is that engineering practices from previous decades become deprecated due to rise of new, faster, and more efficient algorithms taking over (redundant) workloads. This ultimately allows more detailed designing of structures, as more calculations can be made and various, alternative designs can be assessed from a cost-efficiency perspective. In comparison to traditional methods, such level of detail cannot be achieved in reasonable time limits.

In the Netherlands, there is more than 17,000 *km* of dikes and embankments (i.e. levees). Of this total, the Dutch government has the ambition to assess, redesign and finish 50 *km* of levees every year until 2050. Levees are designed and assessed based on the prevention of several failure mechanisms or sufficient compliance with safety standards. These failure mechanisms are captured in technical frameworks defined by Dutch authorities (Rijkswaterstaat 2019). Tools and methods are provided for all relevant failure mechanisms. Scientific institutes and engineering companies use these technical guidelines in their projects to ensure levees comply with widely accepted standard methods. As the technical frameworks are prone to changes due to insights from new projects or research, methods standardized and automated in spreadsheets and scripts need to be modified frequently.

At the moment, a geotechnical engineer typically has the following tasks during projects:

- Soil investigation planning and parameter determination;
- Collecting data based on soil investigations and assessing the quality of this data;
- Schematize subsurface based on soil investigations;
- Choosing one or several normative soil profile(s) and parameters to assign to this profile;
- Setting up and making calculations for multiple failure mechanisms and normative soil profiles;
- Assessing and reporting the calculation results;
- Updating the existing calculations when more data or new information becomes available.

There are many essential tasks in this workflow, which means that the performed work is prone to human errors. The result is that during each task, there is a severe risk for misinterpretation of data or data being misused. This risk is further increased as the tasks are repeated for many cross-section of a levee. There is a certain possibility that the workload of geotechnical engineer will only increase in the near future, there is significant amount of levee to be fully redesigned. With frequent changes in the design standards, new methods are necessary to lower the work load.

In this study, an investigation was conducted to analyse the effects of automation efforts in dike and embankment projects. A case study was set up in a typical levee project to automate stability calculations. The results are compared in terms of qualitative and quantitative differences.

2 METHODOLOGY

2.1 *Software*

The programming language Python (https://www.python.org/), version 3.6.9, was used for calculations, figures, data management and statistical analyses. The general packages used in this research are, among others, NumPy (Oliphant 2007), SciPy (Virtanen et al. 2020) and pandas (McKinney 2011).

The slope stability software D-Stability, developed by the Dutch scientific institute Deltares, (https://www.deltares.nl/en/software/d-stability/) version 20.2.1 was used on a laptop with an I7-8850H CPU @ 2.60 GHZ processor, and 32 GB RAM. Traditionally, project engineers use the Graphical User Interface (GUI) version of D-Stability to set up and make calculations. For automation, the non-GUI version of D-Stability was leveraged, as this version allows the use of parallel processing on multiple cores to decrease calculation time.

2.2 *Application Programming Interface (API)*

Generally, one can assume for (legacy) software with a geotechnical engineering purpose that there are no available means to control or manipulate the software. This type of software is usually not developed for large scale automation purposes but rather for the detailed assessment of a single point, cross-section or three-dimensional area throughout which the geotechnical engineer provides input. During the time of conducting the case study in this research, there was no proper Application Programming Interface (API) available for D-Stability. This was a bottleneck as connection between various data sources and algorithms in Python or other software was needed to automate the stability calculations.

As a result, an API for D-Stability was developed by the project engineers during the case study. This API is part of REAL2.0 (Rapid Engineering Assessment of Levees) which is a software package developed by Fugro. The initial version of REAL1.0 was used for levee assessment, whereas REAL2.0 is focused on designing levees. Fortunately, an open source API is being developed by GEOLIB, a collaboration between Deltares and multiple engineering firms. In general, an API makes it possible to automate tasks such as copy/pasting data, setting up calculations and adding key parameters with the use of code. For this case study, the API was used to create a bridge between Python and D-Stability directly

3 CASE STUDY CULEMBORGSE VEER-BEATRIXSLUIS

3.1 *Introduction*

Along the northside of the river Lek in the Netherlands between Culemborg and the Beatrixsluis (approximately 11 km) some parts of the dike section do not meet the current safety standards. In the preliminary design phase of the Culemborgse Veer – Beatrixsluis (CUB) levee reinforcement project, the dike is re-assessed and an impression is given of the required reinforcement design based on soil investigation and monitoring wells. The failure mechanisms that are relevant to this dike are the inward and outward macro-stability, backward erosion piping, insufficient height and erosion strength of the grass revetment.

In this case study, the focus was on automating the assessment of the failure mechanism of dike macro-instability, as this typically takes the most time during a project. The goal of automation within this project was to efficiently and accurately choose normative soil profiles, and to be able to perform sensitivity analyses by altering input parameters.

3.1.1 *Dike instability assessment in the Netherlands*

In compliance with the Dutch rules and regulation concerning flood protections WBI2017 (Rijkswaterstaat 2019), dike instability in the Netherlands is assessed by means of critical state soil mechanics (CSSM). For undrained soil behaviour, the SHANSEP (Ladd, 1991) model is used to determine the undrained shear strength. With this model the stress history of the soil is taken into account in the determination of the current strength. The stress history is defined either by the Pre-Overburden-Pressure (POP) or over consolidation ratio (OCR), which are determined by the critical state of the soil in comparison to the effective stress in the soil. The undrained shear strength (τ) according to SHANSEP (Ladd, 1991) is defined as shown in equation 1.

$$\tau = \sigma_v' * S * OCR^m, \tag{1}$$

where S [-] and m [-] are strength parameters and σ_v' [kPa] a state parameter.

The strength of drained soils is determined using the Mohr-Coulomb method (equation 2).

$$\tau = c' + \tan(\phi'), \tag{2}$$

where c', the effective cohesion, [kPa] and the effective friction angle ϕ' [°] are determined based on laboratory research. In the critical state cohesion is assumed to be negligible, and therefore equals 0 kPa.

The results of soil investigations and laboratory testing are used to determine the characteristic value of the strength parameters. This is either the low/high 95% value or the 95% estimation of the mean, depending on the type of parameter, the type of problem, and the coverage and extent of the soil investigation. Regular Cone Penetration Tests (CPTs) and borings are used to determine the geotechnical profiles underneath the dikes, from which normative profiles are selected, (profiles with the least favourable conditions). Each profile is assessed with D-Stability and the characteristic strength parameters. The slope failure model used in this case study is Uplift-Van (Van 2001).

To comply with the safety standards, the resistance against instability must be greater than the forces causing instability. Additionally extra safety factors are applied which take into account the uncertainties of the calculation model, material parameters, schematization and possible damage that might occur due to a breach. Conform WBI standards, this results in equation 3.

$$SF \geq SF_{min} = \gamma_n \cdot \gamma_d \cdot \gamma_b \cdot \gamma_m, \tag{3}$$

where SF is the calculated stability factor [-], SF_{min} is the minimum stability factor [-], γ_n is the damage factor [-], γ_d is the model factor (Uplift-Van), γ_b is the schematization factor [-] and γ_m is the material factor [-].

3.1.2 *Data quality and quantity*

For the CUB reinforcement project, CPTs and borings were spaced approximately 100 *m* along the 11 *km* dike section, at the crest, and inward and outward areas. This data was used to determine the geotechnical profiles along the dikes inward and outward toes, and crest.

The soil profile beneath the dike section varies greatly. In the east part of the dike, the cover layer consists of a combination of clay and peat extending to 10 *m* below the surface level, whereas in the middle of the dike section this cover layer is 5 *m* thick. The sandy layer at the bottom does contain some thin clay layers east.

The hydraulic boundary conditions were initially based on the normative high water level and conservative assumptions for the piezometric head in the aquifer. These were updated in later stages of the project due to new data from a monitoring well. The geotechnical profiles were created by InPijn Blokpoel, these were transformed using GIS to an Excel format, for easy application in calculations. At locations where data was lacking (this sometimes occurred in the outer toe), interpolation techniques were used to approximate the soil profile.

The cross-sectional profiles were created using the geotechnical profiles and the digital terrain model for height (based on AHN3). The surface level in the Netherlands is regularly determined using a LiDAR plane and collected in the digital terrain model AHN. At the time of this case study ,the most recent version was AHN3 from 2015. The average offset is 5 cm and the stochastic error is 5 cm, leading to a 95% confidence interval of 15 cm, surrounding the given value. The uncertainty in the schematization of the subsurface depends on the availability of geotechnical data, which in this case has a resolution of approximately 100 meters. In the Netherlands, the heterogeneity in the river lands is large, which is the primary reason why stochastic subsurface models are used for safety assessments.

The strength parameters have been determined by performing triaxial and DSS tests on borehole samples and analysing the CPT's in line with the WBI guidelines. An overview is given of the relevant soil parameters in Table 1, as determined by Van Boven (2020).

Table 1. Characteristic strength parameters as used in the CUB reinforcement project.

	S_{kar}	m_{kar}	φ'/c'	γ/γ_{sat}	POP_{char}
	[-]	[-]	[°]	[kN/m³]	[kPa]
Hard Clay	0.28	0.86	30.2/5	18.4/18.4	20
Soft clay	0.25	0.86	33.5/0	15.5/15.5	15
Peat	0.31	0.83	-	11.0/11.0	21
Clay fill	-	-	27.0/0	17.0/17.0	-
Clay dike	0.25	0.86	30.0/0	18.9/18.9	20
Sand fill	-	-	31.3/0	18.0/20.0	-
Sand	-	-	31.3/0	18.0/20.0	-

In total, 90 cross-sectional profiles were analysed using REAL2.0. A significant benefit was gained by using automation to select the normative profiles. Previously, the computational effort and the time required to perform a detailed analysis for each and every cross-sectional profile outweighed the benefits. However, by automating the stability calculations, it was possible to calculate each cross-sectional profile. From these profiles, 15 cross-sections were selected for further detailed analysis.

3.2 *Algorithm for automation*

For this case study, an algorithm was developed to use the geo-data as input for the stability calculations in D-Stability. The algorithm workflow is shown in Figure 1. The algorithm collects all relevant information (stored in spreadsheets), including the layering (based on geotechnical profiles) at the inner and outer toe of the dike, as well as the crest. The hydraulic boundaries are used to determine the phreatic surface level and the groundwater head along the soil profiles. Materials are assigned based on the material database, consisting of parameters such as the volumetric weight. All this work is performed with Python.

After collecting all the data, the algorithm connects the Python resources with D-Stability by using the developed API. The calculations were subsequently set-up, resulting in various output such as the slope of failure, safety factor etc. Finally, post-processing was done by the algorithm as well by generating figures as appendices. These figures contain all the output data from the stability calculations and were used for quality control by the project engineers to verify the output is as expected. Additionally, project engineers still had the ability to access calculations from the API with the GUI version of D-Stability as the input files for the software were generated by the algorithm as well. Traditionally, setting up the calculations with the extensive amount of data is a tedious task and takes approximately one day per profile. With the algorithm developed in this case study, setting up and calculating all 90 cross-sectional profiles required only 10 *min*.

The algorithm and relevant output of all 90 cross-sectional profiles were used as an initial risk assessment. With the results, it was determined which parts of the dike had the lowest factor of safety and from these normative sections, 15 normative profiles were manually selected for further analysis. After a detailed analysis and clean up by project engineers, the 15 normative profiles were then used in the final levee assessment. In addition to the general assessment, sensitivity analyses were performed with various ranges for soil parameters and hydraulic boundary conditions. the input files for the software were generated by the algorithm as well.

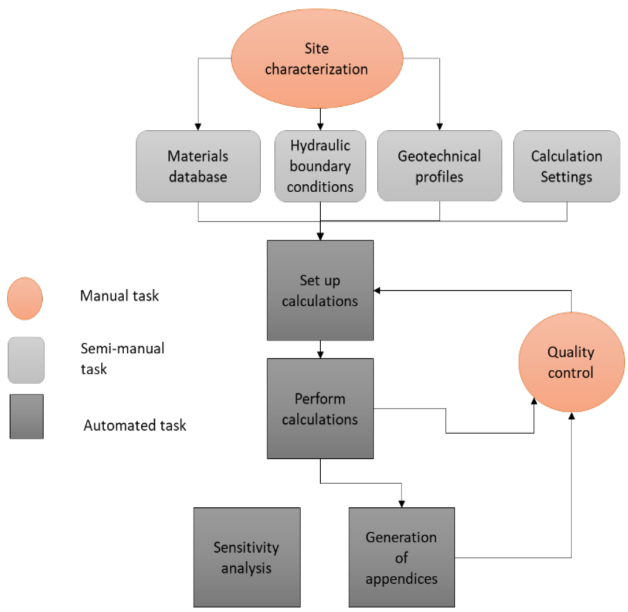

Figure 1. Algorithm workflow as developed for the CUB case study as part of REAL2.0. The calculations are made with D-Stability and the common tasks are done with the use of Python scripts.

3.3 *Results*

In the cross-sectional profiles of the initial risk assessment, the transition between different soil layers was not smoothed by the algorithm. One example of an initial calculation is shown in Figure 2. The same profile was selected as a normative profile and was subject to a thorough quality control/update by a project engineer. In Figure 3. the result of the final calculations is shown.

The main differences between the original and the final reviewed calculations are:

- The application of the heavy clay (i.e. clay with a large density relative to normal clay) instead of the soft clay (i.e. clay with a smaller density relative to normal clay) in the upper part of the cover layer at the outer toe. Upon closer inspection, it was concluded that this layering was present in the input data but an error was made in the transfer step from geotechnical profiles to stability calculation input.
- The application of heavy clay instead of dike clay, underneath the crest of the dike. This was a design choice, as the geotechnical profile does not distinguish "dike clay" as a separate soil.
- The application of heavy clay instead of soft clay at the toe of the dike. The profile in the initial calculation complies with the geotechnical profile, however for the final calculation a different design choice was made.
- The smoothening of the soil layer transitions between the dikes inward, outward and crest areas in the final calculation.
- The piezometric level in the sandy layers was significantly higher in the final calculation due to a conservative design assumption, leading to lower safety factors in comparison to the final calculation.
- The factor of safety varies from 0.75 in the initial calculation to 1.45 in the final calculation. This is due to the factors mentioned, i.e. different design conditions and the availability of more information.

A comparison between the initial calculations and the final calculations for all normative profiles are shown in Figure 4. The systematic shift caused by the semi-manual assignment of soil materials in the outward stability calculations is clearly shown. For the inner stability calculations the changes made are less systematic, however, often soft clay was replaced by heavy clay to better represent reality, thereby improving the calculated stability of the dike. In most calculations the piezometric level was lowered causing the stability of the dike to improve. The piezometric level and the subsoil of the initial calculation were not changed in three profiles. In these calculations, only the soil layer transitions were smoothened, which led to a change in safety factor of less than 0.1.

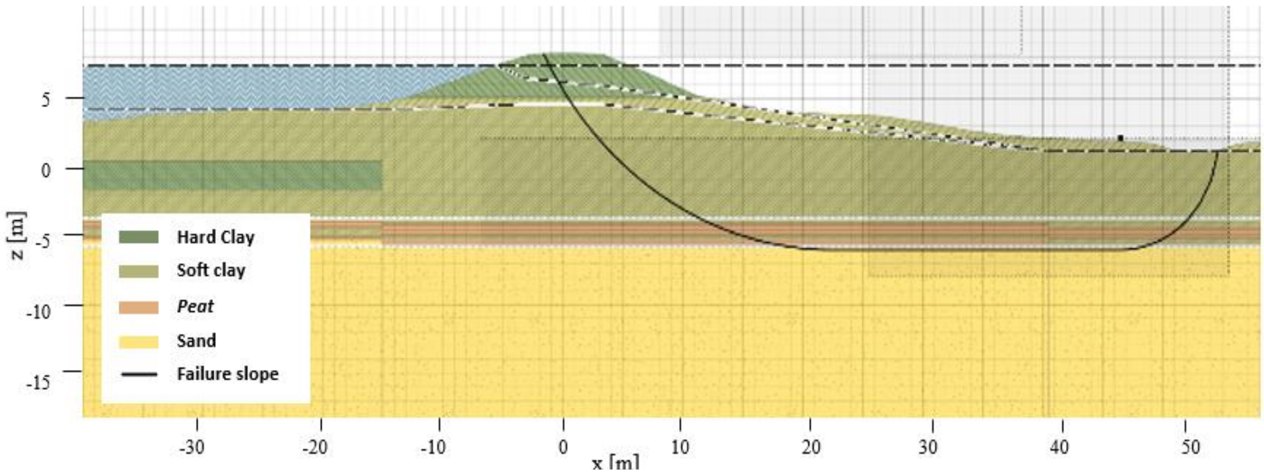

Figure 2. Initial calculation generated with REAL2.0

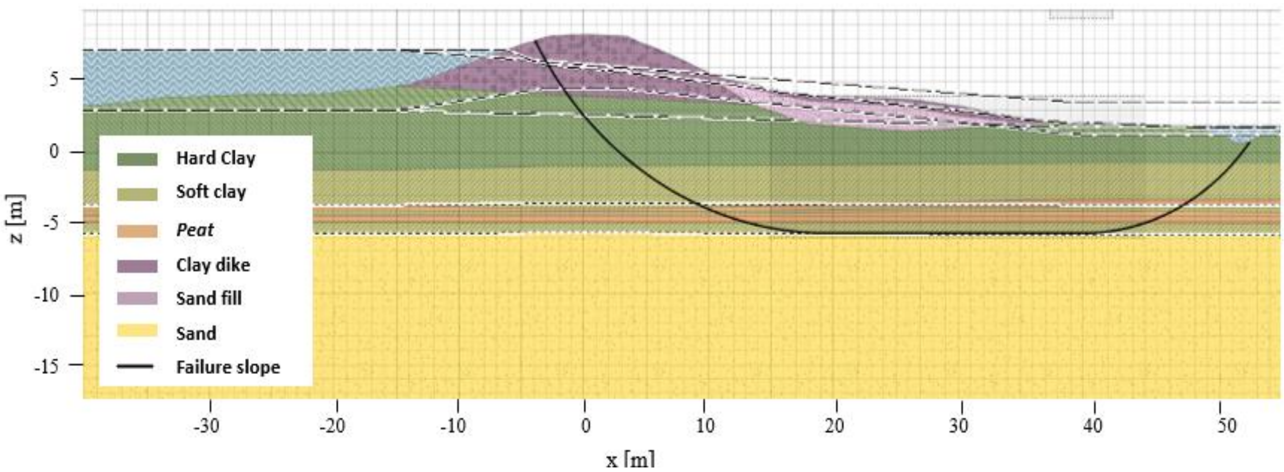

Figure 3. Final calculation after optimization

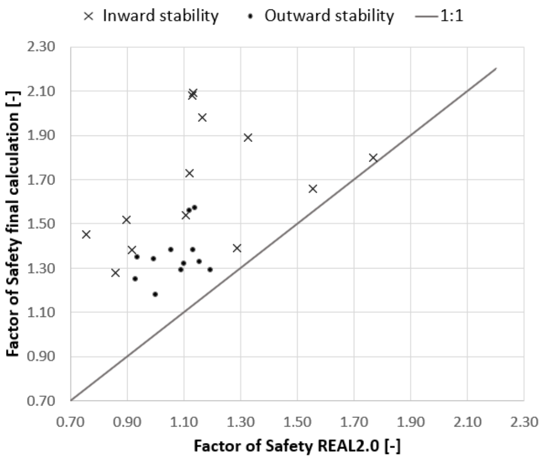

Figure 4. Comparison of safety factors between initial calculations made with REAL2.0 and the final calculations.

3.4 *Conclusions*

The REAL2.0 Python D-Stability class was used as a screening tool to determine the normative profiles, after which more detailed analyses were conducted. In general, the following conclusions were made:

- The output of the algorithm reflect the available input accurately.
- The input data determines the quality of the output of the algorithm.
- This case study shows that for future applications, the algorithm can be used to give a first estimate of the factor of safety.
- By setting the right quality check protocols and enhancing the automatization procedures, automation can lead to the reduction of manual work.
- The time spend on performing and setting up calculations can be reduced from one day per profile to 90 profiles in 10 *min*.
- This case study clearly demonstrates the great importance of quality control, as it resulted in mistakes in the input being discovered and solved.

After the quality control time was saved by automatically performing sensitivity analysis and automatically generating appendices.

4 DISCUSSION

4.1 *Confidence in algorithms*

In general, automation means placing trust in the algorithms that take over the work. This is a difficult discussion and outside the scope of this research, as it concerns mainly psychological effects. However, engineers can gain confidence in algorithms by:

- Being involved in the development of the algorithm. This does not necessarily mean that they need to understand the full algorithm but knowing the high level overview will help to prevent thinking of algorithms as black boxes.
- Using proof of concepts to understand the fine details an algorithm can provide. By changing settings and trying different setups, engineers can understand the algorithm much better and gain trust in using it.
- Leveraging algorithms as tools and not as computers taking over work. Engineers should always be wary of the fact that algorithms are used as a support tool to their work and not something that should fully conduct the work.
- Using benchmarks and visualization to verify the output. In case there are large differences with a manual calculation, engineers can modify the algorithm to ensure it functions correctly.

Regarding algorithms, customer experience indicates that algorithms can be fully trusted when the development and management are properly taken care of. It is understandable that relying on dated code without updated is much more difficult in comparison to using scripts that are regularly updated, including the addition of new features. Furthermore, if new algorithms are developed, wide acceptance follows when these algorithms are sufficiently tested with full customer engagement.

4.2 *Data quality, quantity and assurance*

It is of paramount importance to provide the correct data to algorithms. During the case study, when considering material parameters and geotechnical profiles, the data quality is directly related to the data quantity and the amount of errors it contains. Generally, the more soil investigation is conducted, the more is known about the subsurface, thus resulting in better quality of data.

Data quality should be sufficient. This very much depends on the specific user case, but in general, data can be deemed of high quality if it is consistent, accessible, accurate and useful. Before an organisation considers automation, it is important for them to have the correct processes in place to provide, store and manage good data.

Data quantity is important as well. Data-driven working is only possible if enough data is present. Finally, data assurance is very important, as the data should be consistent and checked for errors to prevent faulty input.

4.3 *Change in responsibilities engineer*

As the processing workloads are managed more by algorithms, this results in a change in the job responsibilities of engineers. A traditional engineer would usually be involved in the data processing and calculations, as well as the analysis of the results. With automation efforts increasing, it is expected that the modern engineer will focus more on the analysis of calculation results, the validity of algorithms and consulting clients by giving advice. This can be seen as a challenge as well, since this type of engineer will need to understand the algorithm in terms of code which requires affinity or a technical background in software engineering and/or computer science. This is often a separate discipline from engineering studies such as civil or geotechnical engineering.

4.4 *Integral approach in projects*

As automation requires the consolidation of many data resources into one system, an integral approach to automation becomes possible. By automating as many design and calculation processes as possible, it is easier to use data with a multi-purpose and increase the return of investment.

With increasing size of the automated workflows, flexibility must be guaranteed. Flexibility of the algorithm can be gained by a modular code setup using a central backbone, to which multiple tools can be connected. Flexibility for the user can be obtained by creating access to intermediate results.

5 CONCLUSIONS

5.1 *Benefits of automation*

Automation leads to the reduction of manual tasks, resulting in an increase of the quality of work. The largest benefit of automation is the time efficiency. An engineer is not required anymore to search for information and manually set up calculations, leaving more time for proper quality control and project consultation.

Furthermore, due to the increase in efficiency in the general workflow, small mistakes or updates in parameters can easily be corrected for an entire project. Reversely, a small error in the input will be noticeable in the entire project, which is why quality control of the input data is one of the most important steps in the new workflow.

5.2 *Limitations of automation*

Automation is limited by data, algorithm and engineer quality. As automation intrinsically means data-driven working, problems will be encountered if data is of insufficient quality.

Furthermore, if the algorithm is limited or not fit to do the job, the required results will not be obtained. Finally, the engineer responsible for the validation of results needs to have a minimum amount of experience to ensure a good quality check.

5.3 *Feasibility of automation*

In general, the feasibility of automation depends on the efforts to invest in developing an algorithm, to properly setup data pipelines ensuring data consistency, and controlling and improving data quality. Furthermore, APIs are not always available for software that is used, which means that by either open source development or co-creative efforts, APIs need to be developed. Automation offers significant benefits but investment is needed by organizations if they want to fully benefit from this revolution.

6 RECOMMENDATIONS

6.1 *Quality control strategy*

To ensure the correctness of the automated process, the quality control step is most important. The control must be thought out prior to automation. What can be considered, are for instance sampling the output or creating a baseline input, with known output, that can be checked after updating the code.

Documentation and validation are key to ensuring the knowledge is passed on correctly. Therefore, it is recommended to plan time for this part of the process. By using visualization of the calculation results in the case study, a significant amount of time can also be saved during the quality control check.

6.2 *Change management practices*

With automation becoming a more prominent part of engineering, the role of the geotechnical engineer changes. It moves from performing calculations to either quality control (both of the input data and the output results), automation/software development or consultancy and giving advice to clients.

To grow the business and increase optimization, it is key that the knowledge of automation is shared. First, by creating awareness of the potential of automation. Second, by training engineers to automate their own manual tasks. And finally, by creating an automation community, where knowledge is shared scripts can be developed together and collaboration can be encouraged.

6.3 *Future applications*

Besides eliminating manual tasks in the future, it is very likely that also the mental tasks by project engineers can be repeated by computers due to developments in artificial intelligence (AI) and machine learning. A full, technically sound design of a levee will be possible in the future with the use of these new tools.

However, this also means that the role of the geotechnical engineer becomes more important. In case geological formations contain anthropogenic layers, physical logic does not hold anymore and it becomes very important that a geotechnical engineer has a critical look on algorithm output. Furthermore, the geotechnical engineer will be more of a decision maker, for instance decisions about housing behind the dike, the environmental and ecological considerations will be to their account. These types of decisions cannot be handled by AI at the moment, since these decisions are not always based on pure logic, but take into account local emotions and politics.

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