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Automated Engineering in Levee Risk Management

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ABSTRACT: The risk of flooding depends on the hydraulic load, strength of the levee and the estimation of flood consequences. To determine automatically the strength of levees, the Dike Analysis Module (DAM) has been developed. This platform is able to perform stability analysis for a large numbers of levees within a management area. In order to show the role of automated engineering in daily levee management, two study cases are presented here. The applicability of DAM is tested with real data. Spatial planning studies as an application of DAM are also discussed.

Keywords: Automated engineering, stability analysis, spatial planning, data management, study cases

1 INTRODUCTION

In many countries, levees play a major role in flood protection and flood risk management. Worldwide, hundreds of thousands of kilometers of levee exist. Often, these levees are old and little is known about their safety. Besides geometrical data, information on the subsoil conditions is of great importance for assessing the reliability of a levee system. In order to cope with this challenge, several programs on data management are currently being developed in the Netherlands.

Data acquired in the field or by geological analyses cannot be used directly in the models used to assess the safety of levees. This data needs to be first processed and filtered before it can serve as input for the models. Recently, the effectiveness and efficiency of data acquisition has advanced considerably. For example, laser scanning has enabled us to obtain topographical information (i.e., levee geometry) of large areas in a very short time. In order to advance at the same pace with the technology, it is necessary to improve also the data processing to enable effective and rapid safety assessments. The Levee Analysis Module (DAM) is a tool that automatically process and analyses the gathered data and can be used to support decision-making.

The required data depends on the goal of the assignment. The requirements during daily circumstances differ from the data necessary for flood control, policy management or levee assessment. The basic information (soil profiles, soil properties and geometries) remain the same for the different processes. The high degree of automation in DAM makes rapid analyses of levee systems on large geographical scale feasible. The degree of detail can vary depending on the goal of the analyses; from very strict in polices to very detailed in real-time assessments for decision support of flood control measures and emergency response.

This paper describes the application of DAM in two cases where the gained analysis capabilities by the automated engineering approach is described. The first case describes the use of REAL-DAM for a levee assessment. The suitability of DAM for spatial planning studies is discussed in the second case.

2 FRAMEWORK

2.1 *Dike Analysis Module*

DAM is a platform for automatically determining probability of levee failure. Based on a given hydraulic load, DAM calculates the strength of a levee automatically. It is a semi 3-dimensional determination of the levee strength. This means that cross sections are schematized from a three-dimensional terrain model complemented with point observations of soil structure. From these cross sections, the stability can be determined.

DAM features a highly modular design. For different applications, a configuration of relevant modules can be composed. The applied modules are dependent on the availability of data and purpose of the stability analysis.

The workflow structure of DAM is based on the four steps of a geotechnical analysis (see Figure 1). The first step is collecting processed data from subsoil models, digital terrain models (DTM) and hydrology models. The data has to be stored in standardized databases. Requirements for data quality and quantity depend on the purpose of the analysis. For example, a design calculation requires more detailed information than policy analysis estimations. In the second step, generic algorithms schematize representative cross sections. Different algorithms can be used. The algorithm selection depends on available data, purpose of the analysis and calculation models. In the Netherlands, for the regular safety assessment, conservative assumptions for schematizations are prescribed in guidelines.

To perform the correct actions during critical water levels, information about the actual levee strength is necessary. The third step is executing the actual stability calculation to determine the levee stability. Due to the modular structure of DAM, different models can be used to calculate the stability. The final step in the process involves the analysis, visualization and reporting of the geotechnical analysis.

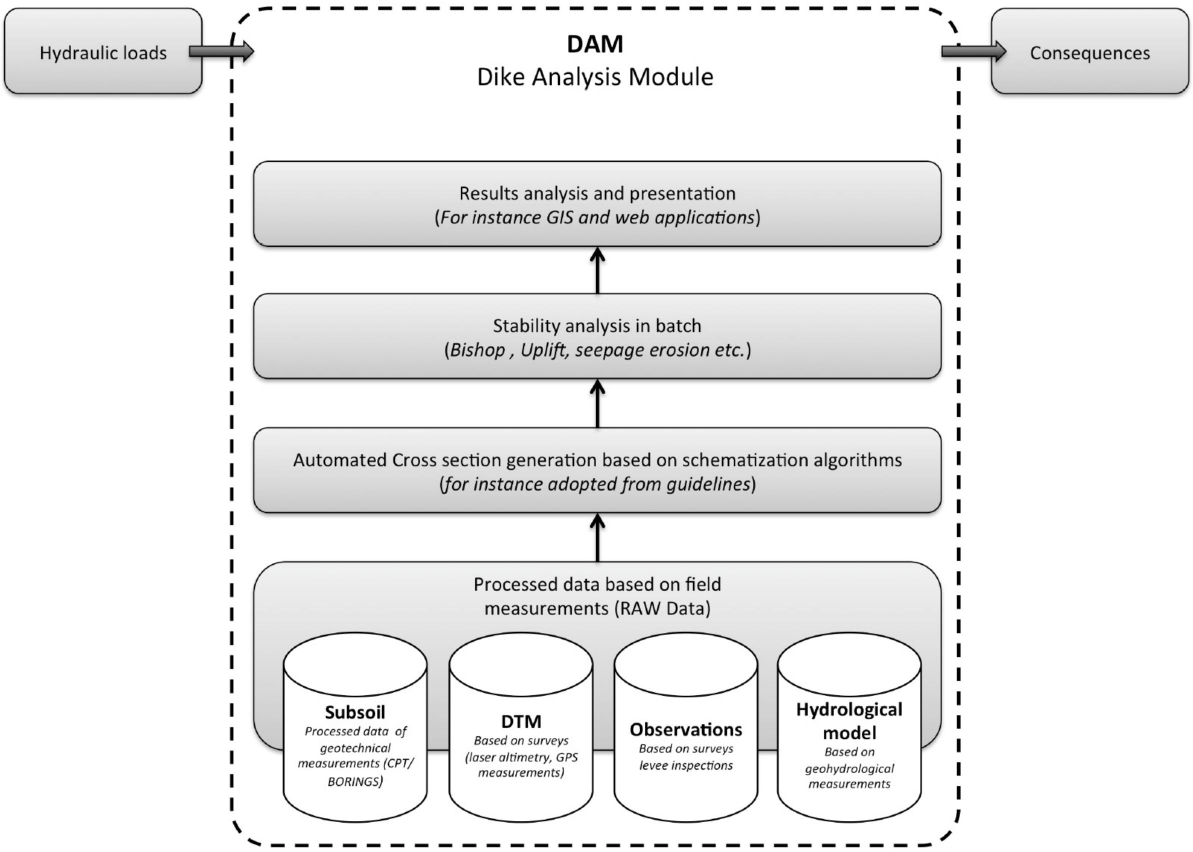

Figure 1. Structure of DAM

Normally, for every analysis the four steps are performed where the emphasis lies on the analysis of a representative cross section of a levee trajectory. For such an analysis, one or more cross sections are measured and several borings and cone penetration tests are performed. If necessary, pore pressures and soil properties are measured. From this data, a representative cross section is schematized and this labor takes a great deal of engineering judgment. Finally, the result of the geotechnical analysis is analogous reported and archived.

DAM assumes that in 21st century data of geometry and subsoil will be stored in digital databases. With clever codes and algorithms, relevant data can be extracted form these databases and automatically schematized for stability and strength analyses. The use of codes and standards reduces the engineering judgment. The schematizations are the input of geotechnical analysis of a levee. Results of the analysis are presented for further analysis in a GIS environment or in the web. In this way, with inbuilt intelligence, the four steps in DAM can be performed automatically in a short time. Real time analysis is even possible in case of a flood risk control.

When new data becomes available, it is simple to replace that particular module in DAM. The same holds for codes and standards. Due to its modular structure, it is not necessary to schematize the cross sections from scratch again, since the algorithms in the software do this automatically.

While using DAM as a platform to perform risk assessments for levee management, distinction is made between risk assessments for normal levee management and assessments for flood risk control. In case of flood risk control, the platform is used to show real-time information of levee strength, possible emergency measures and basic assumptions of the analysis. This article focuses on the risk assessments as part of the normal levee management.

In addition, the central data management promoted by DAM (see Figure 2) maximizes the efficiency of the assessments of the levee manager. Until recently, a levee operator depended on data from colleagues within or outside their organization to perform tests. Central data management allows the levee manager to access actual up to date data at any time.

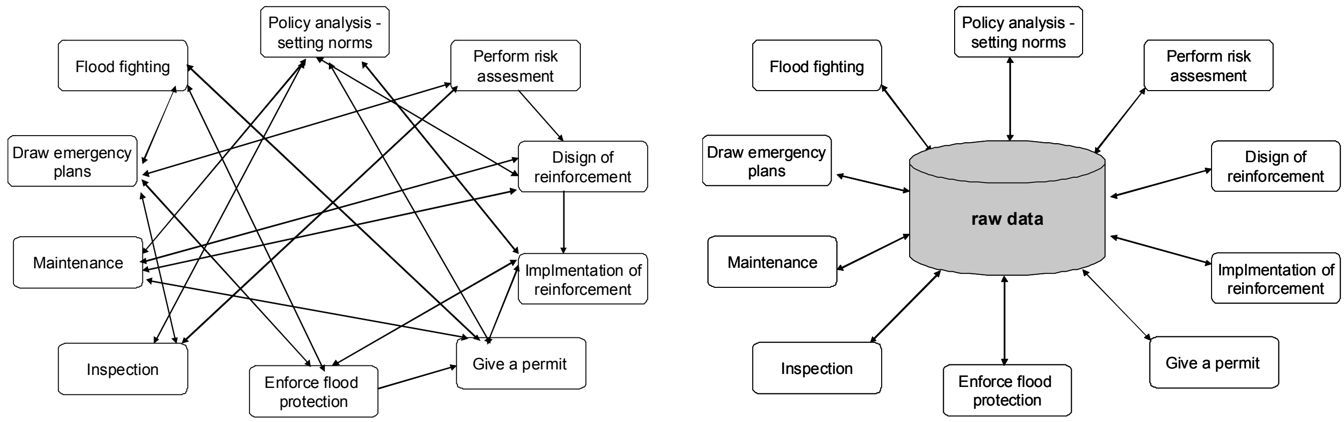

Figure 2. Current data management (left) and central data management structure offered by DAM (right)

2.2 *Levee management*

Figure 3 shows an overview of the processes for normal levee management in the Netherlands. In the figure, various cyclic processes are visible. The outer circle consists of the following processes:

- Setting standards and norms, this process involves determining the conditions that must withstand the levee and the procedures to be followed to show that the levee meets these requirements;
- Risk assessment every 6 years (stated in the law). The risk assessment shows which levees do not meet the requirements;
- Design of levee reinforcements. If levees do not meet the requirements, the levee must be strengthened;
- Implementation of reinforcements.

The inner circles relates to the daily processes with respect to levee management. These processes are related to daily maintenance and space planning.

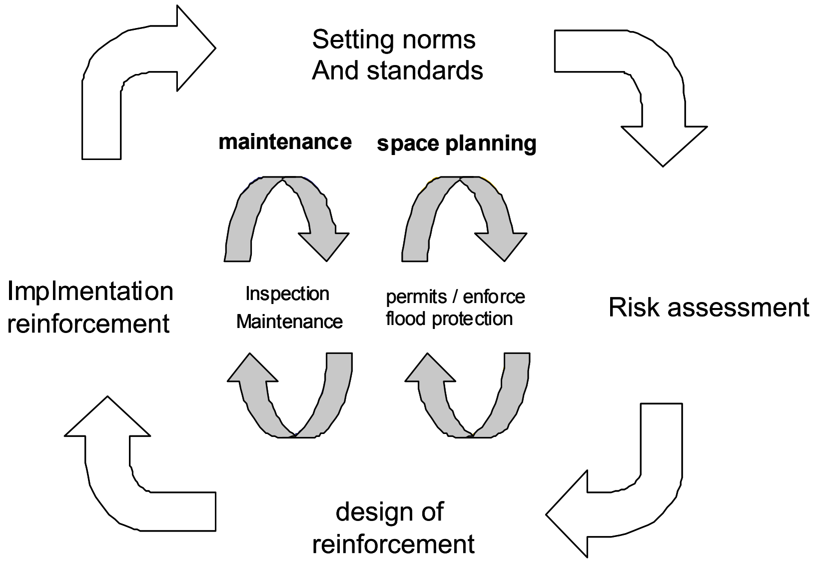

Figure 3. Normal levee management in the Netherlands

Table 2.1 shows an overview of the relation between levee management and the applicability of DAM. For every process, the table describes a purpose and the applicability of DAM.

Table 2.1 Applicability of DAM for different processes around a levee

Process	**Example of application of DAM**
Setting standards and norms for levees	Decision Support System for policy analysis. Quick-scan of possible consequences by changes in the standards and norms. An example is described in case 1
Risk assessment every 6 years	Risk assessment according to obligatory schematization procedures. This procedures are programmed within DAM. Example is described in Knoeff e.a. (2008)
Design of levee reinforcement	Support the choice of preferred alternative of reinforcement. Determines size and cost of levee reinforcement for a 3D-space with different alternatives.
Implementation of Reinforcement	Increase efficiency levee reinforcement. Determination of activities based on real-time levee strength (based on measured pore pressures).
Daily levee maintenance	Feasible maintenance plan. Prioritize maintenance based on available budget and actual risks.
Space planning around a levee	Determine limits of authorization. An example is described in case 2

3 CASE STUDIES

This section describes the application of DAM in three different cases. In the first case, setting of standards and norms in California is studied. The second case, analyses a spatial reservation Waterboard Groot Salland. In the third case, a levee reinforcement is designed.

3.1 *Case 1: Setting standards and norms in California*

Since 1995, a Dutch law enforced a six-year periodic assessment of the water retaining structures in the country. Very recent programs for systematic levee evaluations have been also introduced in the United States. The program FEMA's RiskMAP and the California Urban and Non Urban Levee Evaluation Programs are examples of this.

For the California Urban Evaluation Program, the California Department of Water Resources is facing a major challenge to conduct an appropriate and rapid geotechnical assessment to determine the safety of the levees. To face these challenges, Fugro and Deltares, combined contineous dike strength modelling in

GIS, according the REAL® method[1] with automated engineering provided by the DAM platform . Based on data of the evaluation program, almost 1.000 different levee cross sections are evaluated for three water levels and three failure mechanisms. Using the DAM platform, the speed in calculation is about two orders of magnitude faster than conventional evaluation techniques (Woldringh ea, 2009).

In this project, REAL protocols are used for data collection which is the first step in the analysis as described in section 2. REAL uses available information from a GIS, such as surface levels (digital terrain models), data acquisition with FLI-MAP system; CPT's; borings; water pressure measurements; geotechnical parameters (weight, cohesion, friction angle; geological maps). Information must be provided in digital form, with spatial XYZ coordinates, and preferably in a Geographic Information System (GIS). Using this data (step 2 of the analysis), a most-likely subsoil model is made with the geological knowledge and local experience for a levee compartment. A standardized grid of data is generated on each soil layer. Consequently, the reliability of the subsoil model can be checked and improved in each point, by comparing the layers with underlying (additional) information.

For the computations, the digital terrain model and 3D subsoil model is composed of cross sections every 25 feet. Using the DAM platform, calculations are made (step 3 of the analysis) for 3 different potential failure mechanisms: macro stability landside slope, macro stability waterside slope and internal erosion (piping) for all the cross sections. The results (step 4 of the analysis) of these calculations are then presented in the GIS.

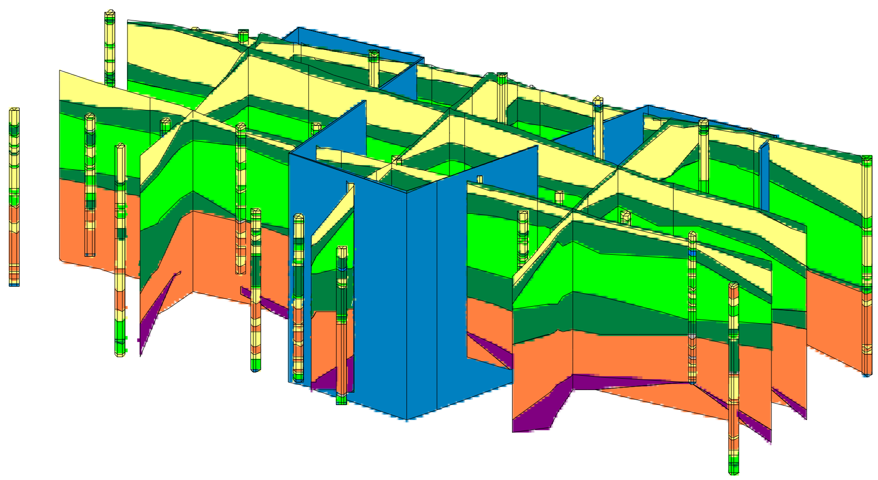

Figure 4. 3-dimensional subsoil model derived from REAL®

The stability of landside and waterside slopes are calculated according to the model of Bishop and Lift-Van with the MStab software. MStab is developed according Dutch standards. In the US, stability is in most cases checked with the method of Spencer.

In addition, there are some important differences between the US and Dutch standards for schematization and analysis of cross sections. For example, in the Netherlands a conventional effective stress analysis is used for the stability assessment of levees. The Californian standards prescribe undrained stress analysis with the SlopeW software. Another example is the estimation of pore pressures. On one hand, when there is no information available on pore pressures, a pre-described method for the schematization of the pore pressures is used in the Netherlands, where expert knowledge is allowed to be used to make a better schematization. For that reason, DAM supports this technique. On the other hand, in California pore pressures are calculated by different software called SEEP/W.

However, the objective of this project is not to assess the levees but to demonstrate automated engineering. Therefore, the MStab software and Dutch schematization of pore pressures is used where SlopeW can be easily linked to DAM due to its modularity.

[1] Rapid Engineering Assessment of Levees

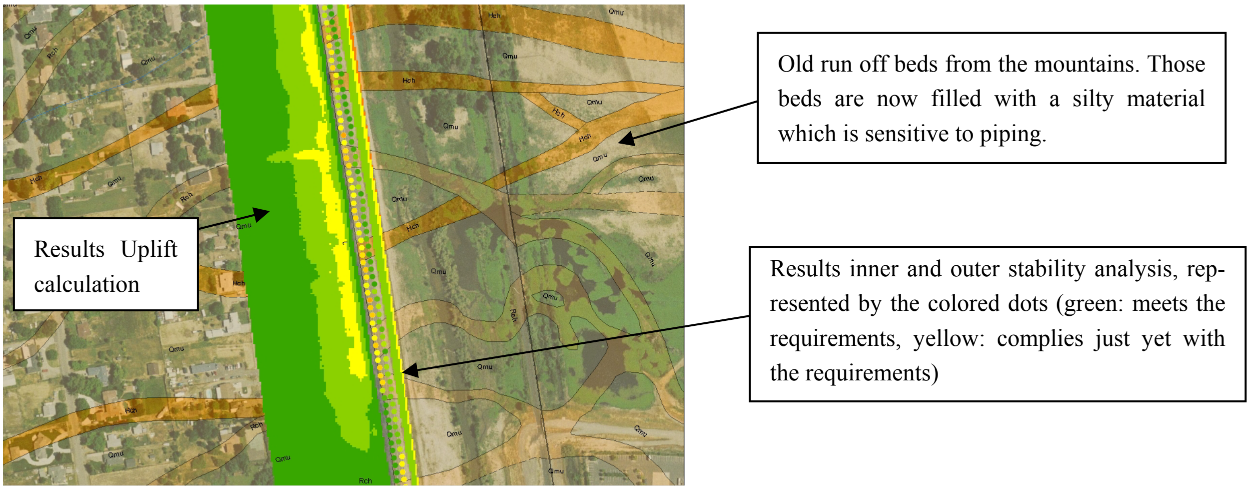

Figure 5. Results of REAL™ analysis

Despite the differences between the US and Dutch standards, a comparison is made between the stability analyses for the 'official' levee program and the results DAM calculations by Deltares. Calculations of three cross sections (approximately every 750 feet) are made. The slip circles of the selected locations are compared with the DAM slip circles. In general, the position of the slip circle is comparable but the computed the safety factors are different. However, the difference decreases when the DAM calculations are made with estimated drained strength parameters for clay layers. From these results, it is possible to observe that in California many raw data is used in analyses. On this respect, DAM with little effort could translates this raw data into the information needed (levee strength).

3.2 *Case 2: Spatial reservation Waterboard Groot Salland*

Around a levee in The Netherlands different zones are defined; core zone, protection zone and outer protection zone. Within these zones, different rules are applied to protect the levee. For instance, it is prohibited to build within a zone without a permit. As described by Koelewijn & Hounjet (2007), there are three main reasons for the preservation of sometimes-precious space on both sides of a levee: maintaining the flood protection function now and in the future, avoiding damage to other functions arising from rehabilitation works necessary in the future an creating opportunities to avoid casualties in case of failure of the embankment under extreme conditions. The spatial reservation is divided in different zones and administratively determined in the so-called "Legger".

In the Netherlands, normally the zones are defined based on a "rule of thumb". For instance, for the landward side of the levee a reservation of 30 meters is made from the ditch behind the levee or 60 meters from the inner crest line in cases where no ditch exists (Koelewijn & Hounjet, 2007).

The pressure on the available space around a levee increases every day due to lack of space and building plans. In addition, in urban areas often constructions like houses, are present in the vicinity of levees. To achieve an optimum definition of the zones and thus the spatial use, the use of a rule of thumb to define conservative spatial reservations is not applicable anymore.

To optimize the zones, and get a better legal basis to the issue of space reservation around the levee, detailed stability analyses should be performed. By using the traditional calculation methods, the costs would be extremely high. DAM, however, is a valuable tool that can be used in this case to execute the calculations.

As described before, the zones are determined based on slope stability and seepage erosion calculations for the current situation. Information such as the situation for the year 2100, with changing hydraulic conditions (due to climate change) and settlement of the subsoil is also include for the analysis.

The analysis is performed in the following step: stability analysis of the current profile (see 3.2.1), assessment of the minimal required geometry for current situation (see 3.2.2) and assessment of the minimal required geometry for the year 2100 (see 3.2.2). After performing the calculations, the results are reported in a visual way in subsection 3.2.3.

3.2.1 *Stability analysis current profile*

The first step is to determine the actual stability of the levee as it is. In this case study, this is done with DAM. DAM uses the data from the databases of the water board, as described in section 2. Based on this data and schematization algorithms, DAM is capable of automatically generate cross sections and perform stability analyses. As mentioned, the data scenarios are equal for all steps.

3.2.2 *Determining minimal required geometry for current situation*

To determine the minimum required levee geometry for the hydraulic loads of the year 2011, first an initial profile is defined. The next step is to determine the minimal required levee profile with respect to levee safety, based on the hydraulic loads for the year 2011. In normal engineering practice, this is done by setting up a model in a computer program. This is followed by a change in the geometry by hand, until the results of the stability analysis match the required safety factor. This is an intensive process and consumes a lot of time. In addition, in case of changing parameters, the process must be done allover again. Setting up the schematization and changing the geometry is automated in DAM and consists out of different steps.

The first step is checking if the height of the levee matches the required height, based on the hydraulic loads. For the case that the crest height is to low, the levee is heightened automatically. Here, algorithms are used to define the height of the phreatic plane based on guide lines, as well as expert knowledge and measurements. After completing the schematization, a stability analysis is performed. In case the derived safety factor meets the required safety factor, the batch process is stopped. The generated geometry is equal to the minimal required geometry. If the assessed safety factor is to low, DAM changes the geometry. Depending on the exit point of the slip circle, DAM changes the angle of the inner slope or creates a berm. If the exit point of the slip circle lies on the inner slope of the Levee, DAM changes the slope steepness to avoid not normative slip circles. To achieve this, DAM increases the slope width in steps until sufficient safety is found, or until the added width reaches a certain maximum (default 15 m.).

In case of adding a berm, the used algorithm is based on shifting the starting point along a straight line with a predefined slope (see Figure 6). The slope has a default ratio 1:3 (vertical:horizontal). The ratio can be altered in the configuration file. The starting point could be the inner toe of the levee or the outer crest of an already existing berm. The shifting process is performed in steps. The horizontal component of the shift and the maximum number of steps are configurable. The shifting process is repeated until a safe geometry is found which meets the required safety factor. This is an iterative process. This profile is exported to the database for further reporting.

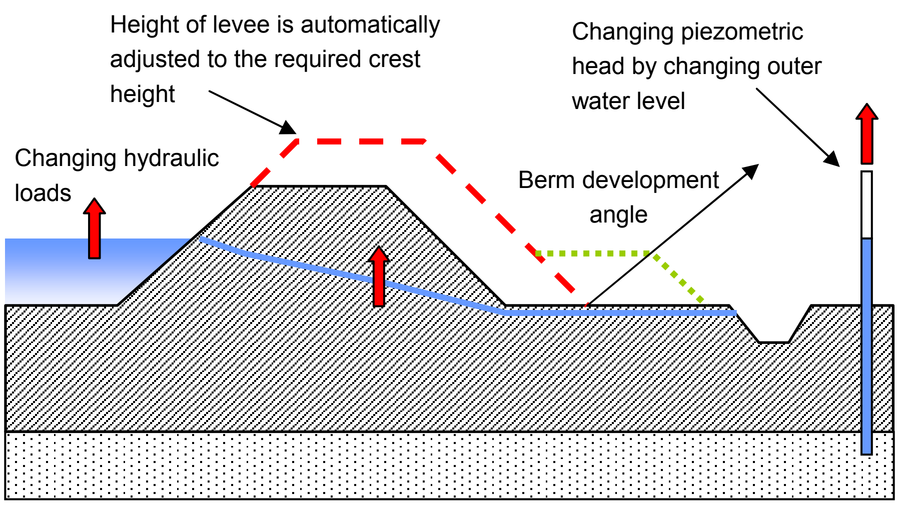

Figure 6. Automated geometry adjustments within DAM

3.2.3 *Determining minimal required geometry for the year 2100*

This calculation procedure is alike to the one described in subsection 3.2.2, only the values of the hydraulic loads and required levee height are different. This means that only some minor changes are made to perform the analysis for the year 2100. Other necessary data for performing the calculations is equal to the data used for the previous calculations. This means that the same database, for instance the subsoil model, can be used by DAM to generate the cross sections.

3.2.4 *Results*

After performing the calculations and optimizing the geometry to match the required safety factor, the adjusted profiles are exported and combined per cross section. In this way, it is possible to visualize the required minimum profiles for the space reservation (see Figure 7). In addition, characteristic points like the crest lines and toes of the levee can be plotted in a aerial map.

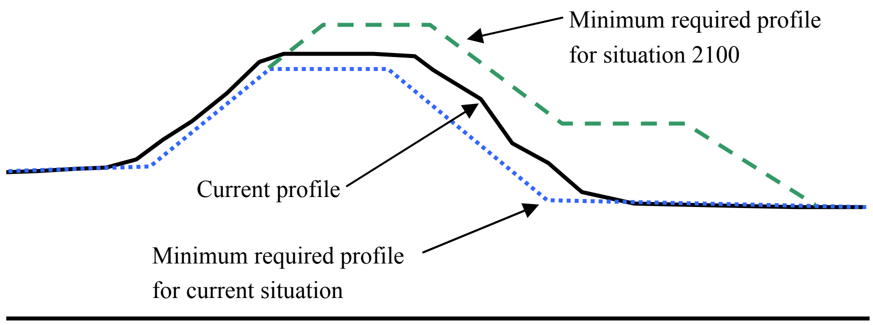

Figure 7. Example where the diffent determinde profiles with DAM are combined in one drawing

Based on the applicability of DAM, the Waterboard[2] considers to use DAM for their risk assessments. Due to the detail level of the employed databases, it is expected that the data used for defining the "Legger" can be used as well for the 6 yearly assessment of regional levees.

4 CONCLUSION

Based on the case studies here presented, it can be concluded that automated engineering can be used to optimize and automate different processes around levee management. Main advantages of automated engineering are:

- Legal management to the issue of space reservation around the levee by performing detailed stability analyses to define the different protection zones on a higher detail level.
- Transparent decisions based on comparable results and a transparent workflow and processes. It is easy to follow the different schematization steps (in the basic no engineering judgments).
- Efficient use of the feasible data (more calculations are performed). Different processes use the same databases. This prevents the use of outdated data.
- Due to the modular configuration of DAM it is quite easy to hook up other models to DAM or other guidelines. This makes the system suitable to use in different countries with different models and procedures.

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[2] The Waterboard is a public organization in The Netherlands responsible for levee management.