Damage risk assessment of buildings due to dike strengthening

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1 Abstract

Due to rising sea-levels and global warming the Dutch flood protection system has been re-evaluated and new requirements for dike-safety have been set. The 10 km long IJsseldijk, close to the city of Rotterdam, has been re-evaluated and needs strengthening.

Before starting the design, an important boundary condition has to be investigated: the 1200 small and large buildings on top and alongside the dike. The site conditions include very soft soil (peat and organic clay) in combination with a high and fluctuating ground water level. In cooperation with the local water board (Hoogheemraadschap van Schieland en de Krimpenerwaard) a damage assessment is made of the buildings due to different construction effects, such as ground works (deformations) and the installation of sheet piles (vibrations).

A detailed investigation concerning the building characteristics has been executed, blank spots were filled in based on correlations with known attributes, using for instance Insar satellite data. Based on these building properties the risk of damage for each building has been calculated based on a number of simple geometrical rules. This resulted in a database with a first (qualitative) assessment to make the preliminary design.

After designing four alternatives for dike strengthening, the risk of damage has been re-evaluated. For multiple locations the risk of damage for the different alternatives has been calculated, both for deformation and vibrations (quantitative assessment). Using the derived correlations and the building characteristics, these calculation results have been translated to all buildings within the project area. The paper describes the interaction between geotechnical analysis and data management in order to support the decision process in finding the optimal dike strengthening alternative.

2 Introduction

For the project KIJK (in Dutch "*Krachtige IJsseldijken Krimpenerwaard*") the assignment is to make a damage risk assessment for the buildings on top and alongside the dike and to use these results in the decision making of the preferred design. Two analyses are performed in order to quickly feed the design and decision making process with relevant data. In the first, qualitative, assessment the risk of damaging the buildings caused by construction effects is determined before knowing the boundary conditions for the dike strengthening design. Geometrical and general design rules are used to have a first quick assessment.

The second, quantitative, assessment consists of using boundary conditions based on calculations for representative situations of the four design alternatives, ground conditions, foundation and type of buildings. The results of the calculations are projected on all situations on the dike using different classification which makes it possible to assess the risk of damage for each individual building in the project area. The damage risk assessment is an integral part of the Multi Criteria Analysis which results in the preferred dike strengthening design.

3 Qualitative damage risk assessment

3.1 Data acquisition

The damage risk analysis is performed for two construction effects, groundworks and the installation of sheet piles. The first leads to deformations and the latter mainly to vibrations (the risk of settlement due to vibration of sheet pile walls is limited in this case), both can cause damage to the buildings.

For both effects the risk of damaging the buildings is based on multiple parameters "distance to construction works, position in the dike, state of building, type and material superstructure and type and material foundation".

To determine the parameters for each building a large data acquisition campaign is executed. To effectively and efficiently collect the data multiple sources were consulted.

Municipal data (Land Registry and Mapping Agency)
Registered municipal data can be freely accessed through the website of the Dutch Land Registry and Mapping Agency. It contains information about the buildings exact location (with coordinates), address, year in which it is build and the monumental status.

Satellite data (InSAR)
InSAR satellite information is used to collect the natural deformation of the area over the past three years. With these deformation measurements the time-

settlement behaviour of the buildings has been analysed with a high precision. The time-settlement behaviour is a good indicator of the state of the foundation or foundation type.

Fig. 1: Satellite data (InSAR)

Archive investigation

Specific data of the buildings is essential to have a better understanding of the state in which the building is and how sensitive the buildings are for damage. In the local municipal archives data is acquired about the type (pile or shallow foundation) and material of foundation and superstructure.

Visual inspections

Visual inspections are performed to get a better understanding of the area and the buildings. The result is a photograph of each building (taken from the public road), an estimation of the amount and wideness of cracks, repairs, the condition of maintenance and where the building is located in reference to the dike.

Fig. 2: A church that was build in the dike

3.2 Factsheet

The collected factual data is stored in a database from which a factsheet for each individual building is processed. These factsheets are used to inform the inhabitants and companies on the progress of our investigation and to acquire more data from them which we were unable to find in the sources. The response to the factsheet is very positive and plays a positive role in raising the awareness for the dike project.

Factsheet - Damage Risk Analysis KIJK (Krachtige IJsseldijken Krimpenerwaard)			
Adress:	Kattendijk	Number:	1
Postal code:	2831AA	City:	Gouderak
Municipal data (BAG)		**Monumentally protected status**	
BAGnumber:	644200002073600	Distance to dike axis [m]:	22.8
Buildingtype:	residence	Hectometre dike axis [km]:	37.3
Function:	other user functions	**InSAR-measurements**	
Building year:	1880	Time-Settlement [mm/year]:	-2
Archive investigation	Information present:	yes	
Foundation type:	piles	Materiaal vloeren:	-
Foundation material:	concrete / Steel	Calculations present:	no
Installation depth:	referencelevel -16,5m to -20,0m	Drawings present:	yes, the pilefoundation plan
Basement present:	no		
Type superstructure:	masonry		
Notes archive investigation			
Foundation has been restored in the past			
Visual inspections		date:	1-12-2016
Tilted walls [visual]:	no	Material outer walls	masonry
Cracks in walls [visual]:	moderate	Reparations visible:	yes
Condition of maintenance:	moderate	Position to dike:	hinterland
Notes visual inspection:			
-			
Classificatie			
Classification SBR-A:	3		
Vibration sensitive foundation:	no		
Notes			

Fig. 3: Factsheet

3.3 Correlation and classification

A large amount of factual data has been acquired, however not for all the buildings. In order to enhance the data density, correlations are derived between for instance age of the building, autonomous settlement (based on satellite data) and foundation type and material.

The difference between the factual and correlated data should be used with some care. Depending on how critical the design will interact with the correlated data verification by additional investigation should be considered.
Based on the data acquired on the building properties, the sensitivity of the buildings to vibrations and deformations is defined and classified.

3.4 Results

The qualitative risk assessment of the buildings is based on the factual and correlated data and the distance between the building and the dike. The factual and analysed data, as well as the classifications, is used in combination with the geometrical characteristics (distance to dike position relative to the dike) to determine the risk of damage by using a weighing-system for the different parameters. The higher the score, the higher the risk of damaging the building becomes. Using a database proved to be very effective in implementing the weighing-system and automatically determine the qualitative risk of damage for each building. All data and results are visualized with a geographic information system (GIS) to give a efficient and effective presentation of the results.

4 Quantitative damage risk assessment

4.1 Introduction

Simultaneous with the qualitative part of the risk analysis, four alternatives for dike strengthening are designed. The alternatives are shown in figure 4 (left to right):

1. Dike strengthening with ground works;
2. A combination of groundworks and a sheet pile (type II construction)
3. A sheet pile which fulfils both height and stability safety (type I construction)
4. Dike strengthening with groundworks by moving the axis therefor creating a “new” dike next to the existing one

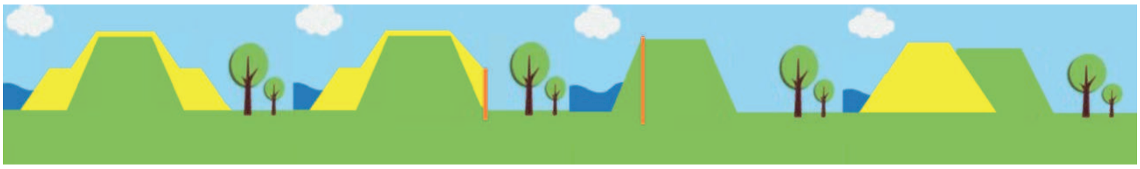

Fig. 4: Four alternative designs

For several representative buildings, the risk of damage is calculated for each of the four alternative designs. The deformation is calculated using finite element software PLAXIS and the risk of damage according to Netzel (2009). The vibrations caused by the installation of sheet piles is calculated using the CUR166 method, which is primarily based on CPT data and the type of sheet pile. The risk of damaging the building by vibration is determined with SBR-A (2003).

Design boundary conditions have been derived from the results of representative buildings, which makes it possible to perform a damage risk assessment for all the 1200 buildings.

4.2 Risk of damage due to vibration

The vibrations, caused by the installation of sheet piles, depends on the type and length of the sheet pile as well as the soil in which it will be installed. With finite element software the length en type of sheet pile for construction type I and II are calculated. The theoretical energy required to install the sheet piles to the designed depth is calculated with an analytical method according to Dutch CUR166 design recommendation.

The risk of damage due to vibrations is described in the Dutch “SBR-A” design recommendation. Different, frequency dependent, vibration limit levels are set for these categories. When the actual or predicted vibrations stay within the limit levels, the risk of damage is less than 1%. For each building a specific zone of influence has been calculated and verified for all alternatives.

4.3 Risk of damage due to deformations

The risk of damaging the buildings due to ground deformation is calculated using finite element software Plaxis2D. To have an overall estimation of the soil displacements for a large number of buildings 20 representative situations are modelled, with an accurate profile of the dike and the bathometry of the river as shown in figure 5.

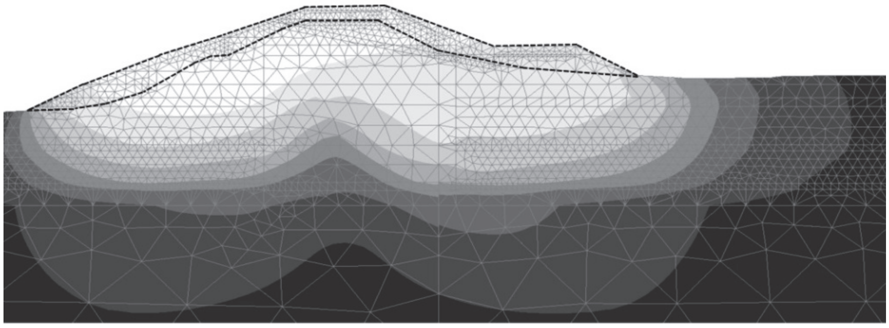

Fig. 5: Dike strengthening with ground works

Based on Netzel (2009) the greenfield-displacements, the buildings are not modelled, are imposed on the building using the limiting tensile strain method. The amount of deformation imposed on the building depends on the foundation type. For a shallow foundation the imposed displacements are considered to be 100%. For pile foundations only a part of the greenfield deformation will act on the building itself by the dragdown force the soil has on the pile (negative skin friction). The percentages that have been used are based on literature and the Amsterdam North/South line project data analysed by CRUX. For wooden and concrete piles respectively 20% and 7% of the vertical displacement will act on the building itself. A safe upper limit for the horizontal displacement factor is 50%.

The risk of damage is calculated based on the limiting tensile strain method. This analysis is described in ‘Building response due to ground movements’ by Holger Netzel. The risk is categorized using the BRE-classification, from structural damage to the more favourable esthetical damage. This exercise has been done for 10 different buildings along the dike for all four alternatives.
The distance between the buildings and the dike axis, e.g. the distance to the dike strengthening alternatives, is known in the database. This is combined with geometrical data (distance between dike, construction method and building) to asses risk of damage, as illustrated in figure 6.

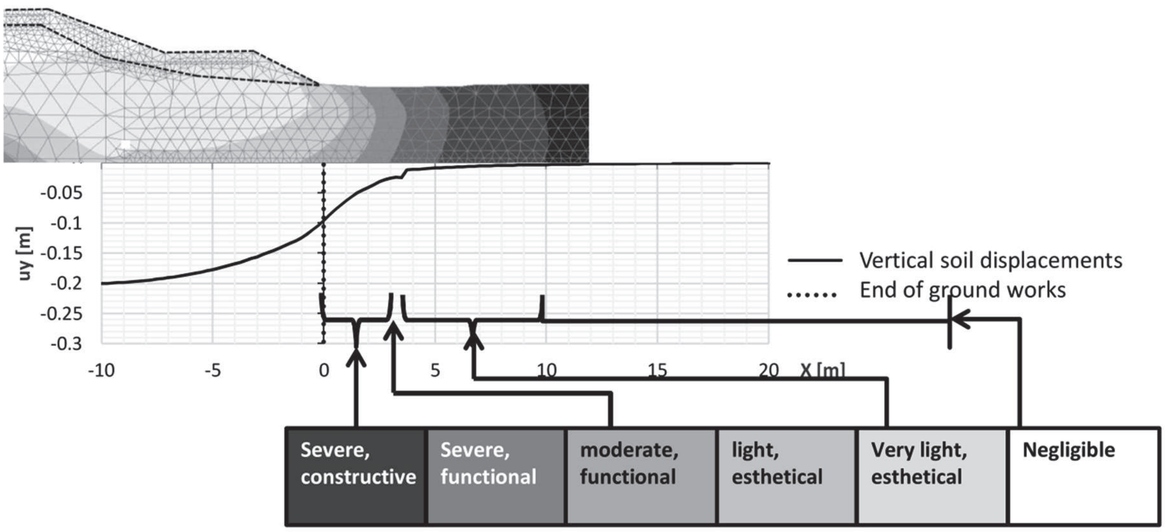

Fig. 6: Categorized risk due to dike strengthening with groundworks

Using the factual and analysed data and the calculation results for the dike strengthening design alternatives the risk of damage for each building is determined. In figure 7 this process is presented.

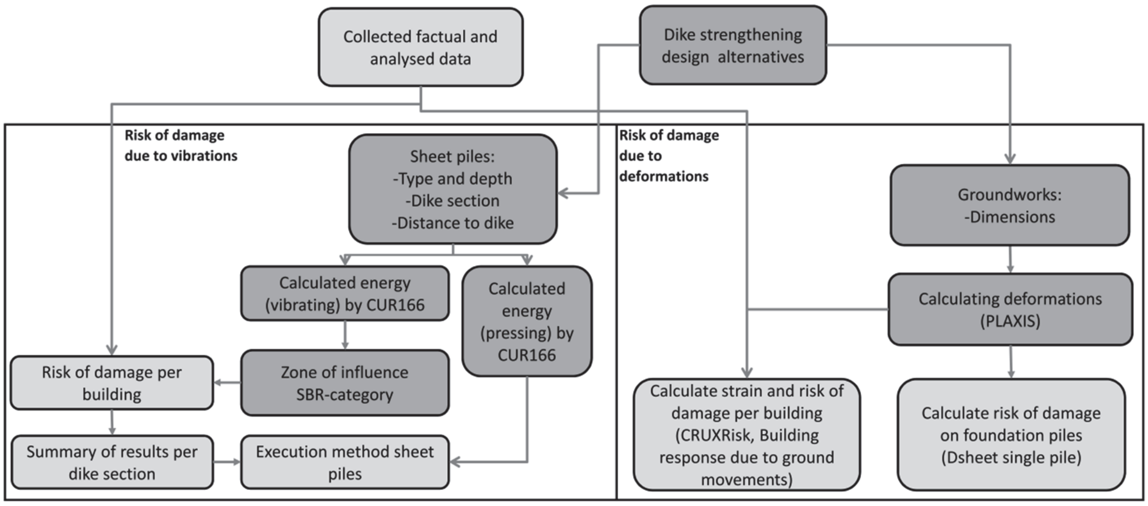

Fig. 7: Damage risk assessment

4.4 Results

By analysing the results from the calculations a few conclusions are made which are used in the MCA.

Dike strengthening with groundworks
The use of groundworks results in large horizontal and vertical deformations. Depending on the exact amount of ground work and the distance to the building this can either result in no damage, acceptable damage, non-acceptable damage or having to remove the whole building.

A combination of groundworks and a sheet pile (type II construction)
By using a sheet pile type II construction, the amount of groundworks can be reduced, which will also reduce the deformations. For installation of the sheet piles vibrations will occur, however because the sheet pile do not have to been installed in the Pleistocene sand the acceleration of the vibrations are relatively low.

A sheet pile which fulfils both height and stability safety (type I construction)
When using only sheet piles and no groundworks there are far less soil displacements which can damage the buildings. However in all cases the sheet pile needs to be installed in the Pleistocene sand, which will cause considerable vibration acceleration to the buildings.

Dike strengthening with groundworks by moving the axis therefor creating a "new" dike next to the existing one
Changing the axis and creating a "new" dike can only be applied when shifting the axis towards the riverside. When there are no buildings located on the outer-

and inner slope or on the foreland the risk of damaging is very low but this can only be applied where there is enough space in the river itself.

5 Preferred design

The risk of damaging the building is determined with the acquired data, the four alternative designs and the results from the calculations. The results of the damage risk analysis are embedded in the Multi Criteria Analysis and this results in choosing the preferred dike strengthening design. For the cost estimate measures to prevent damage (not altering the design) are also taken into account.

5.1 Mitigating measures

Preventing damage is preferred to repairing damaged buildings. So multiple 'mitigating measures' are designed to prevent or minimize the risk of damage to buildings. Instead of using a vibrating hammer a static hydraulic press can be used to install sheet piles to reduce the risk of damage by vibrations. The risk of damage by deformations can by reduced by minimising the volume of the added soil by sheet-piles (like a type II construction). It is also possible to design a stiffer structure to reduce displacements. A few 'standard' measures are designed to prevent damage.

If an alternative seems feasible for a whole section except for one or a cluster of buildings it is an option to choose another alternative for that small part or to choose to demolish and rebuild the structures. The last solution needs a lot of consensus with the inhabitants.
The mitigating measures are taken into account for the cost estimate to establish a sound comparison between the different alternative designs.

5.2 MCA and cost estimate

The risk of damage or even the overlap of buildings with the reinforced dike profile is an important criteria for the Multi Criteria Analysis (MCA) and cost estimate. For multiple sections of the dike the risk of damaging buildings turned out to be an important criteria.

The designed mitigating measures are not used in the MCA, but are used in the cost estimate for all alternatives and the final design. For some alternatives the costs of all the measures to prevent damage seemed to be quite large compared with the total costs.

6 Conclusions and recommendations

By consulting useful sources data can be acquired at a early stage in the project to make a qualitative damage risk analysis of the buildings without having the dike strengthening design. Building a database is essential to efficiently and effectively analyse the data. The database is used to classify how sensitive buildings are to vibrations and deformations and to inform and interact with the inhabitants and companies that are located on and near the dike.

After designing four dike strengthening alternatives, which consist of using sheet piles and/or groundworks, a quantitative damage risk analysis is performed. In this second analysis the chance of damage is calculated according to Netzel (2009) and SBR-A (2003) for each of the four alternative designs. Calculations are made for several characteristic buildings which is translated to assess the risk damage for each individual building using correlations and the database.
To determine the preferred design, mitigating measures are defined which can be used when the traditional methods have too high of a risk in damaging the buildings.

The four alternative designs, the results from the damage risk analysis and the costs of mitigating measures are analysed in the Multi Criteria Analysis (MCA) and the preferred design, for each section of the dike, is defined.
To come to a efficient and effective design for dike strengthening, which consumes a lot of time, it is important to set the right boundary conditions at a early stage of the project. By collecting data and setting up a database which can be combined with the design properties we have a powerful tool to determine the design boundary conditions when taking the risk of damaging the buildings into account.

Fig.8 : Damage risk assessment for design alternative four

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