Assessment of risks for the TEO project Federation Island Sochi, Black Sea

The required soil improvement for the breakwaters

Bachelor research Civil Engineering

J.J.H. Tromp

Enschede, March 2009

Witteveen + Bos

Universiteit Twente
de ondernemende universiteit

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Final report

Bachelor research Civil Engineering

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Preface

This report is the result of my three months Bachelor research at Witteveen+Bos Russia in Saint Petersburg. The research is the last part of my Bachelor Civil Engineering at the University of Twente and will allow me to start with the next phase of my education program. The internship helped me implement and expend the knowledge obtained during my bachelor program.

I have done several assignments for Witteveen+Bos. Creating the risk assessment for the TEO project Federation Island was of course my main assignment and I have spent most of my time on this project. Next to this I helped with the current matters and projects of the office, which did not allow me to get bored.

Personally I can look back at a very good internship period at Witteveen+Bos. First of all I learned a lot more about technical design and solutions, which is the core business of Witteveen+Bos Russia. Next to this I learned to work in a small office with very diverse personal, who all helped enthusiastically with my research. Therefore I am very proud to have been part of this team.

I would very much like to thank my supervisors, Dr. S.H.S. Aljibouri and Ir. A.J.G. Kops. Also specially I want to thank my supervisors in Saint Petersburg Erik Schulte Fischendick and Arnoud Joling. They both helped me feel like home and were very helpful with my research. Next to this I want to thank my other colleagues, who helped my find my way in the city and made my stay abroad interesting and pleasant.

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Management summary

Critical to the construction of the Federation Island project in Sochi, Russian Federation, is the soil improvement needed under the breakwaters. To improve the soil different methods and techniques can be used, which all have their own characteristics. Furthermore, these methods and techniques can have different influence on the project outcomes, which are construction time and cost for the construction of the island breakwaters.

The goal of this research was to determine and asses the risks on the construction of the Federations Island's breakwaters. To achieve this goal first a detailed research of possible soil improvement methods and techniques was done, after which the best two techniques were computed in a simulation model. The model was developed in a modular manner, allowing it to be useful for later phases of this project or for other projects. A literature study, a web search and by consulting experts of different companies the required input data, information for the model and data for the risk analyses was collected.

The first part of the research led to two soil improvement techniques, which can be used for this project. Namely;

-The double lock gravel pump method
-The blanket method

These techniques are respectively a offshore bottom feed stone column and a wet top feed stone column method. For the research the process of producing stone columns was modelled in Excel and it was assumed that for both techniques the top layer of the to improve soil had to be dredged. This led for both techniques to the following process steps:

-Mobilisation of equipment
-Dredge top silt layer
-Transport and dump/overload gravel
-Production of stone columns
-Demobilisation of equipment

The research focussed on the project outcomes time and costs, which are also the Excel model outcomes.

The second part of the research is the determination and analysis of the project related risks. First uncertainties are determined by a process of risk identification, which is based on a literature study, a web search and by consulting experts of different companies. The list of uncertainties produced by the risk identification was discussed with experts within Witteveen+Bos to determine a final list of risks, which was used in the risk analysis. For the analysis the program Crystal Ball was used to simulate the effects of the risks on the project outcomes, using the Excel model and risk distributions.

The risk analysis showed that the effect of the risks on the total project duration is positive, because the total project duration is expected to be shorter than the total project duration modelled in Excel. The analysis also showed that the effect of the risks on the total project costs is negative, because the total project costs is expected to be higher than the total project costs modelled in Excel. Also the analysis showed that the stone column diameter, the length of the production area and the C.T.C. distance are the most influential risks on both project outcomes.

The sensitivity analysis showed that the C.T.C. distance, the length of the production area, the stone column length and the stone column diameter have the most influence on the project outcomes. All these uncertainties are directly related to the soil parameters, which makes the influence of soil parameters the main risk for this project. Next to this the reliability of the production values for producing stone columns is an important risk, because the activity of producing stone columns is important in the critical time path of the production schedule.

For the future of the project it is important to get more accurate information about the soil parameters, which can be obtained by a reliable soil investigation. Next to this it also is important to get more reliable production values for both stone column techniques, because the production of stone columns is the most time consuming activity on the critical path of the schedule. This makes it also recommendable to research the possibility to use more sets of equipment for producing stone columns. From the research it was also concluded that the time estimate of 80 weeks for soil improvement is not feasible, which will have its influence on the overall project planning, so the last recommendation of this research is to review the overall project planning.

Introduction

This report is the result of a Bachelor research at the Dutch engineering consult Witteveen+Bos. Witteveen+Bos has approximately 800 employees, divided over 12 different offices around the world. The company has a wide range of specialists, covering projects in water, infrastructure, environment, special development and construction. Witteveen+Bos provides comprehensive services for all phases in a project, from developing the initial concept to project completion and maintenance.

In Saint Petersburg the department Witteveen+Bos Russia is located, which is responsible for the project in the Russian Federation. This bachelor research was carried out at Witteveen+Bos Russia and prepared at Witteveen+Bos in Deventer. The most important project of Witteveen+Bos Russia is the preparation and design of the Federation Island.

The Federation Island project is a large land reclamation project in the Black Sea near Sochi. The reclamation project comprises a main island (250 ha.), surrounded by several smaller islands, protected by three breakwaters. The project is further specified in Chapter 1.

Critical to the construction of the Federation Island is the soil improvement needed under the construction area of the breakwaters. Due to the lack of detailed information, the large dimensions and poor soil conditions of the project area there are uncertainties in the construction of these breakwaters. Goal of this research is to determine and asses the risks on the construction of the Federations Island's breakwaters.

To reach this goal first the research framework is given in chapter 2. In chapter 3 the research will fall back on existing literature to determine the best suitable soil improvement techniques. For the risk assessment a model had to be made, this model is described in chapter 4. In chapter 5 the model was first tested manually to get a better idea and feeling with the model and the possible outcomes. In chapter 6 and 7 the Risk identification and Risk analyses are described, which finally led to the conclusion and recommendations in chapter 8.

Chapter 1 Federation Island

The Federation Island project is a large land reclamation project in the Black Sea near Sochi, which is in the southern of Russia. The island will be shaped like the Russian Federation and will be a 250-hectare artificial island. The reclamation comprises a main island, several smaller island and three breakwaters to protect the islands.
Since the 2014 Winter Olympics are also in Sochi, the project development company M-industry want the island to be finished before this date.

Figure1 **Master plan Federation Island, Sochi.**

After the Master plan was created, a three stage counting TEO-project was started by M-industry. The scope of work for Witteveen+Bos pertained in general to the first two stages of this project, where the first stage is the preparation of substantiation materials used for the project. And the second stage the development of a main design concepts for island and breakwater, with objective to prepare a number of concepts amongst others in terms of costs and construction time.
The results of these stages will be studied on feasibility, which is now being prepared by a third party.

In the first stage Witteveen+Bos has collected and analysed data required to make a conceptual design in the next stage. In the analysis the most important topic where soil investigation and the setup of a computer model for the hydraulic boundary conditions and earthquake model.

The first stage led to a design, which could be divided in four elements. Namely the island, the breakwater, soil improvement and the islands. Where for every phase two options remained and have been worked out in the deliverables of the main design. Due to the large area and high complexity it was decided to make soil improvement a separate phase.

The sub-soils in the Federation Island project area comprise a certain amount of soft soils, which have to be improved. The available soil investigation results (see ref[5]) indicated that the top-layer are silts with very low strength.

When building on this soil without additional measures the following geotechnical failure mechanisms are expected(see ref[5]):

-instability of embankments
-liquefaction of the silt layers during an earthquake
-large settlements

The two design solutions for the soft soil improvement are presented in this research and the design solutions are evaluated and compared based on time and cost. In the soil improvement stage a global planning and cost estimate was made by experts, which will also be evaluated in this report.

The TEO project will be finished by the feasibility study, after which the project development company will chose a number of concepts which will be developed in the next stage of the project. This next stage is the design phase of the project, wherein the chosen concepts are being designed on high detail level. After which the project can be constructed, when the detailed design has been finished.

Organisation of the project
The Russian firm M-industry contracted Witteveen+Bos and Institute 23 to perform the TEO project of Federation Island. The first two stages and the third stage have to be completed, before the next stage of the project will continue. This stage will occur in a detailed design, which is the last stage before constructing the island.

As described the TEO project is divided in three stages:

1. Substantiation documentation
2. Main design concepts
3. Feasibility study

Where the first two stages are performed by Witteveen+Bos and the third stage by Institute 23. In figure 2 the organisation is structured and depicted for every participant.

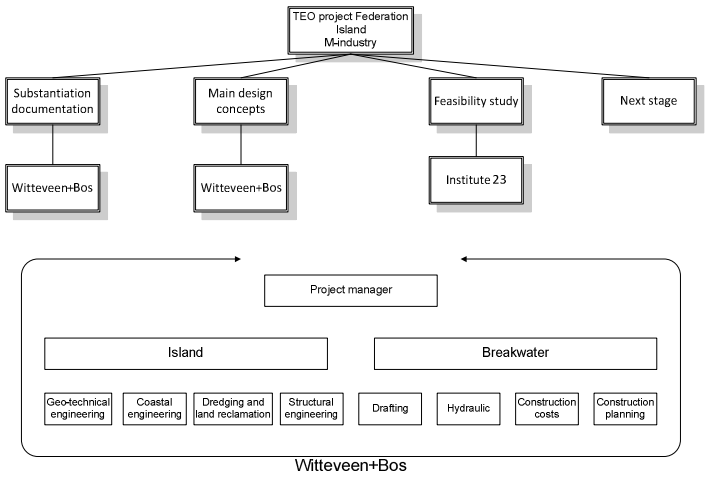

Figure 2: Project organisation

The figure also displays the organisation structure of the project within Witteveen+Bos. Where the project is divided in the project management and the two main project groups. These main project groups are the island and the breakwater project group. As described by the figure these two project groups are also divided in four different sub groups, to finally connect the project to the different profession groups within the organisation structure of Witteveen+Bos.

Chapter 2 Research framework

The soil improvement is critical in the construction of the Federations Island breakwaters, but within Witteveen+Bos there is not that much information available about different techniques of soil improvement. The reason for this research is first of all to get better insight in suitable techniques for this specific project. Next to this it is for Witteveen+Bos very important to know what influence different soil improvement techniques have on the total project time and costs, which is the reason for determining and assessing the risk of different techniques on these project outcomes.
In this section the objectives and research questions will further be described. After which the research method is explained.

Personal objective
My objective is to learn to focus on the part of Civil Engineering, which has my particular interest. Also I want to learn more about foreign cultures and especially the influence Dutch engineers have on world-wide projects. My final objective is to work on a large scale project.

Research objective
"To determine and analyse the important risks that can influence the project delivery when using a stone column method"

Research question
To achieve the research goal, research questions are formulated. These research questions are divided into main questions, as well as in sub questions.

1. What are the main methods that can be used in soil improvement?
    a. What are the characteristics of the Stone Column technique.
    b. What are the existing problems of the Stone Column technique.
    c. What are the risks and their effects on the Stone Column technique.
2. What influence do soil improvement techniques have on the time estimate of experts?
    a. What are the given risks for the planning process.
3. What influence do soil improvement techniques have on the cost estimate of experts?
    a. What are the given risks for the cost estimate?
4. What possible improvements can be made to the process within the Stone Column technique.

Research method
To be able to answer the research questions, a model was developed. This model was developed using EXCEL and Crystal Ball, an add-in simulation program for excel. To develop the model and answer the research questions, the research was divided in different phases. These phases where performed in a cyclic manner, as shown in Figure 3.

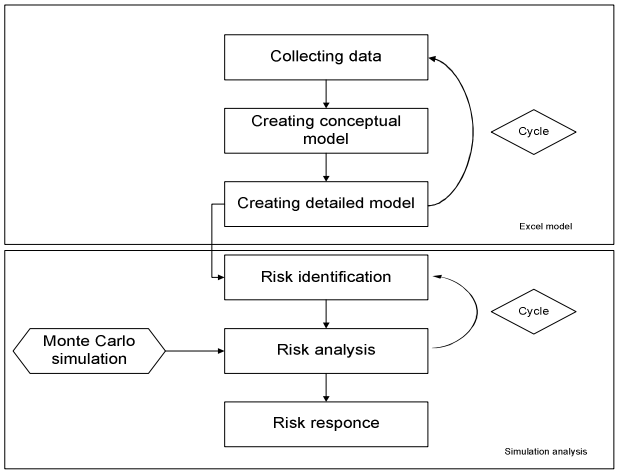

Figure 3: Phases of the research

Data collection is needed to gain insight in the relevant processes to be able to model them and to gather input data for the model. This was done using a literature study, an internet search and by consulting experts. Using the data collected during this phase two alternative methods for producing stone columns were developed.
During the cyclic modelling process, the model moved from a course to a detailed model. In each modelling cycle, the model was first designed on a conceptual level and translated to a detailed time and costs model. The model has its output in total project time and costs and was programmed using EXCEL. For a detailed description of the model see chapter 4.

For the simulation analysis the program Crystal ball was used to simulate output data. Critical in this process was the identification of the uncertainty in input variables. For the simulation analysis the Monte Carlo simulation technique was used. This is a technique based on repeating a process many times, but with random start values.
The uncertainties were identified using the models input data, a literature study, a web search and by consulting experts. This led to a list of possible risks and minimal and maximal values for the specific variables. Statistical distributions were assumed, to describe the bilateral relationship between the minimal en maximal values.

Before performing the simulation runs the excel model was verified and validated. Verification was done by comparing the excel model, by running the model step-by-step(chapter 5) and comparing the output of these steps with calculations of project deliverables(see ref [3] and ref [4]). Validation was done by reviewing the modelled processes and checking model outcomes with experts. In the following this method of validation will be described as “face-validation”. Only this method of validation was achieved, other methods could not be carried out because no statistical data of the processes are available. For more detailed information of verification and validation see chapter 4.5.

The simulation analysis was done in two cycles. The goal of the first cycle was to reduce the number of input variables. The results of these runs are purely for comparative purposes and were discussed with Witteveen+Bos. The remaining alternatives were then simulated “in detail” using a Monte Carlo simulation and a sensitivity analysis on the input parameters was performed. This simulation analysis will be described in chapter 7.

Chapter 3 Theoretical framework

The soil investigation(see ref[5]) revealed that a large part of the island is covered by material that is indicated as silty materials. In Appendix A a three-dimensional model of the soil composition is included, where the soft soil is illustrated as layer 1a and 1b. The both layers can be described as sandy-loamy silt and loamy silt(see ref[3](p.9-10)). This led to the conclusion that for engineering purpose the layers 1a has to be dredged and disposed of and that the strength parameters of layer 1b have to be improved. Without additional measures these low strength parameters will lead to stability problems, which eventually will cause the construction to collapse(see ref[3]).

As described above the main design illustrated two options for soil improvement(see ref[3]). These option, are;

-Soil replacement: Excavation of soft soil and backfilling with soil with the required properties
-In situ soil improvement: improvement of the properties of soft soil

For this case the first solution is not feasible, because the soft soil can only be replaced by sand or gravel. Both materials are not available at the project site, so they have to be imported. This is not a solution, because all the gravel and sand has to come from a long distance(ref[3]).

This chapter will discuss in situ soil improvement on a more detailed level and this will lead to the choice of the soil improvement techniques. These techniques are used in the simulation analysis, to determine the project time and cost for both techniques.

3.1Determination of construction methods

The options for in situ soil improvement are presented in figure 4 below. All of these techniques make use of one or more of the following mechanisms:

-Improve strength
-Improve density
-Improve drainage characteristics
-Increase lateral stresses

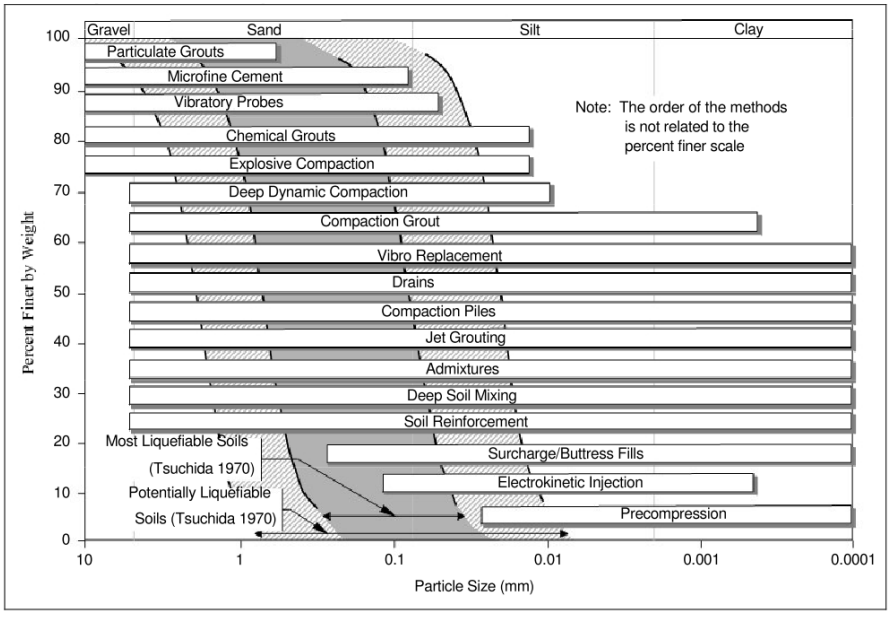

Figure 4 Soil improvement techniques

In figure 4 the techniques are organised in four soil specific categories, namely gravel; sand; silt and clay. In this project the soil can be described as silty-material, which lead to the in table 1 given list of possible techniques. These techniques are evaluated based on six factors, which lead to the most suitable technique. The techniques are evaluated by experts based on literature(see ref[13] and ref[10]), earlier experience of sub-contractors and the below given project characteristics(see table 1);

-Silty soil from which the exact grain size distribution is not available
-The soil layer has low strength parameters and low relative density
-The technique shall be used up to water depths up to 30 m
-Thickness layer that shall be improved larger than 20 m
-Large volumes to be improved

	improve-ment shear strength	effectiveness as liquefac-tion preven-tive measure	cost per m3	production rate per m3	applicable at waterdepth 30 m	proven concept for seismic loading
compaction grouting	+	0	--	+	+	-
vibro replacement	+	+	-	-	0	+
drains	-	0	+	+	0	-
compaction piles	+	+	-	-	0	+
jet grouting	0	0	--	+	+	+
admixtures	+	+	--	-	+	-
deep soil mixing	+	0	--	+	+	-
soil reinforcement	+	-	--	-	-	-
temporary surcharge	0	0	-	--	--	0

Table 1: Evaluation soil improvement techniques

The experts concluded that only vibro replacement and grouting are the only suitable techniques for this project(see ref[3]). Where the grouting technique is especially applicable for small-scale projects. So experts stated that in this specific situation vibro replacement is the best solution. This due to three reasons; First the technique compacts the soil and reduces liquefaction potential, which increases the overall strength of the soil. Second the stone column acts as a vertical drainage, which discharges pore pressure needed during for example Earthquakes. Third the inserted gravel increases the strength of the soil.

Vibro replacement can best be described using literature, which describe it as a method of installing compacted columns of granular material in all types of soils using a depth vibrator(see ref[13]). The compacted columns of granular will further be described as stone columns. Also there are several variants of the vibro replacement method, which are(see ref[13]):

-Wet top feed stone column method
-Dry bottom feed stone column method
-Offshore bottom feed stone column method

Wet top feed stone column method
This method uses high-pressure water jets and vibro penetration to install the stone columns. A vibrator penetrates with aid of water jets in to the ground, to create a hole. After which a prepared blanket of gravel is allowed to fall in the given hole, which creates the stone column.

Dry bottom feed stone column method
This method uses vibro penetration on basis of its self weight to install the stone columns. A vibrator penetrates in to the ground, to create a hole. After which the gravel is dropped down the vibro pile, to create the stone column.

Offshore bottom feed stone column method
This method is similar to the dry bottom feed stone column method, but using this method the above described process will occur from an offshore barge.

3.2 The process of stone column production

A closer look at the project will lead to two possible methods, because the stone columns have to be installed offshore. This will mean that only the "Wet top feed method" and the "Offshore bottom feed method" can be used. In addition to this only a few companies developed these methods into useful systems.
Therefore only two systems can be used for producing stone columns with the earlier described project characteristics. Namely the blanket method and the double lock gravel pump method(see ref[8]). The restrictive factor in this is the soil, because the soil conditions of the soil are very fluid.

The systems are basically the same, because they both use penetration techniques to produce stone columns. Only the steps in producing is completely different, therefore the process of the systems will be described in the following section.

3.2.1 Blanket method

The Blanket method can be divided in two steps. First a gravel blanket has to be placed on the seabed. Second a barge with a crane and vibroprobe is suspended over the gravel blanket, which creates the actual stone columns.

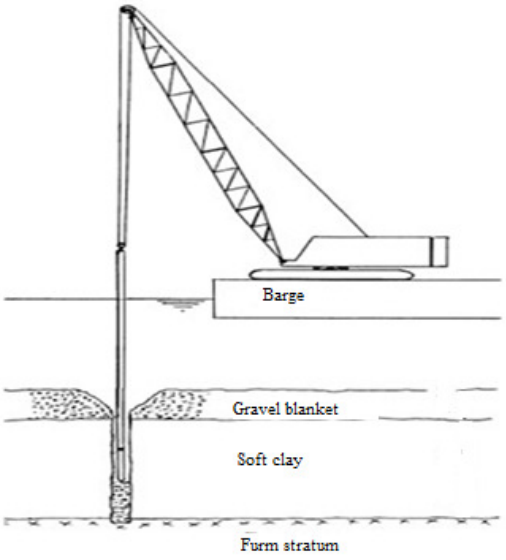

Figure 5: Blanket method

Using vibration and jetting water, the vibroprobe penetrates the gravel blanket into the soil. First the viborprobe will operate a washing operation(see ref 14), in which the probe will be moved up and down to create an annular space. This process is repeated till the hole has the right diameter, after

which the probe will be penetrated to the full depth of the hole. The probe will eventually be took out of the hole in short upward stages, so the gravel from the blanket can slowly slide true the annual space to the bottom of the hole. After the probe has fully been removed from the hole the stone column is completed(see ref[8]).

3.2.2 Double lock gravel pump method

This method is especially designed to produce stone columns on high offshore depths. The process is different as in the blanket method one continues process. For the process the following units are necessary.

-Production barge
-Double lock gravel pump and vibro probe
-Crane on tracks
-Gravel pump with hose
-Receiver tank for gravel
-Long beam crane
-Gravel stock barge

In the below given figure the complete set of equipment is illustrated.

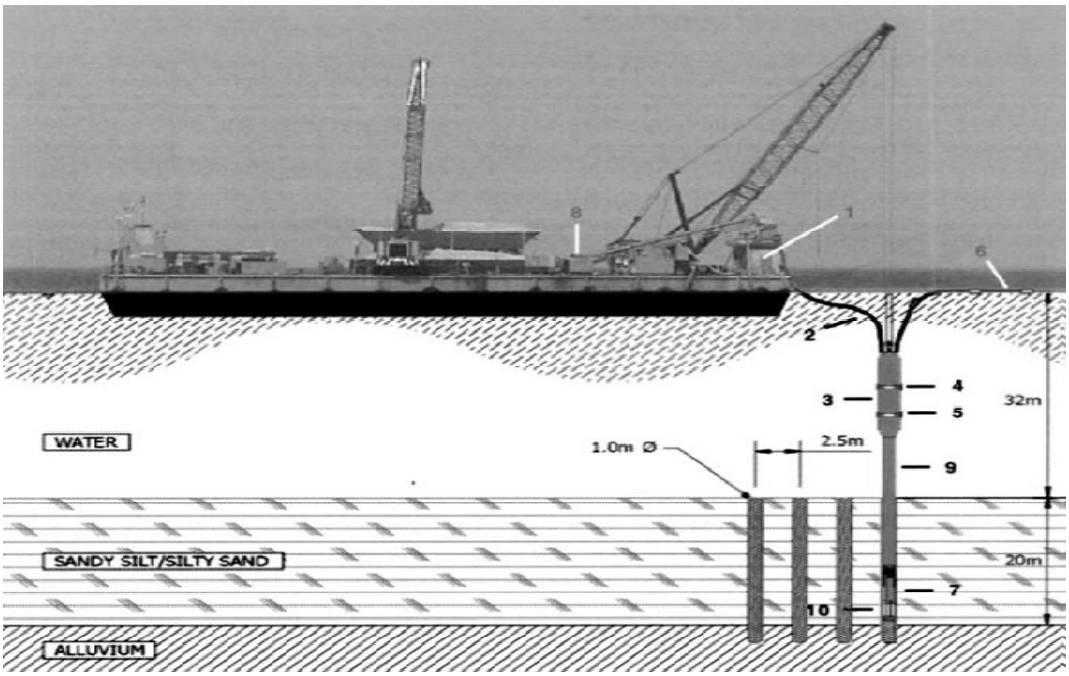

Figure 6: Double lock gravel method

The first step in the process of producing stone columns is penetration of the vibro probe to the given depth of the stone column. During this process the probe will be penetrating the ground due its self weight and constant air pressure will avoid intrusion of the soil to the probe. After the probe is at the right depth the probe will be took out of the soil in small upward stage, in which the gravel pump will pump the gravel true the tip of the probe in to the prepared hole. The gravel is pumped true the probe using the same air pressure to avoid intrusion of the probe. After the probe is totally taken out of the hole, the stone column is finished(see ref[8]).

Chapter 4 A model of constructing stone columns

A model was developed to determine the time and costs requirements for producing stone columns with the Blanket as well as the Double lock gravel method. In the first paragraph the required activities of both techniques will be described. The gathered data were used to determine the relations between the required activities and will be described in the second section.

Based on the required output of the model, simplifications and assumptions were made after which the total project time and costs can be determined. Before the excel model could be used for the analysis, it has to be verified and validated, to ensure that it gives and realistic outcomes.

4.1 Define activities

In the process of producing stone columns, the general phases are the same for both methods. They both require the same input materials and deliver the same output product.
Therefore the activity scheme is in general also similar, but in detail they are essential difference. In figure 7 the global activity scheme is given, which was as a basis used for the more detailed scheme for both methods. For both soil improvement methods the detailed scheme will be described in the following part of this section.

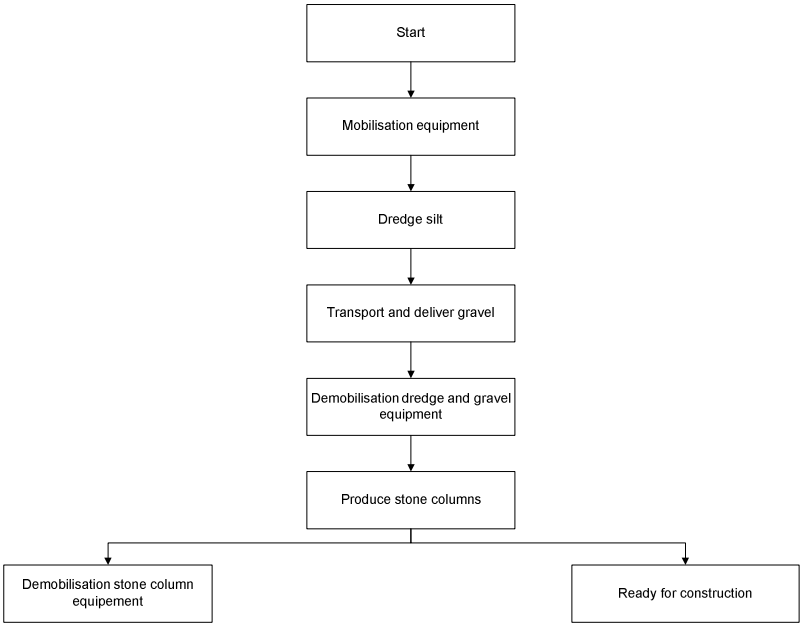

Figure 7: Producing stone columns

4.1.1 Double lock gravel method

In figure 7 just the basic steps are shown in producing stone columns. For both production methods, the realisation of the general steps are different. So in this paragraph the general steps will be divided in smaller steps, to get better understanding of the double lock gravel method.

Mobilisation/demobilisation equipment

To work in Russia a long process has to be followed, before it is actually allowed to perform a commercial job. This is process of requesting permits, filling in forms and arranging documents. Of course this is an important factor, but for this research not of any value. This has no direct influence on the planning and finance of producing stone columns, because all are preparations which have to

be handled before the production process can begin. Also these preparations are all the responsibility of the contractors, which have to ensure this process.
In this research the mobilisation of equipment is seen as the process of sailing to the project site, getting border clearance and getting installed for production. In case of the demobilisation it is the same process, except it is the other way round. So getting the equipment transport ready, moving through border clearance and sail to the next destination.

Dredge silt
In the Black Sea, on the project site, a soft silt layers was found. Especially the top layer is of very low quality, so it was concluded that this layer had to be dredged away. In this case the silt had to be dredged at the project site and dumped at the reclamation area somewhere in the Black Sea. For this reason the only useful equipment used is the Trailer Suction Hopper Dredger (TSHD), because this can dredge the silt, transport it and can dump it without any additional equipment.
In the given figure the process is illustrated. Wherein first the silt is being dredged, using one or multiple suction pipes. After this process is completed the TSHD can transport the dredged silt and dump it through bottom doors at the dumping spot.

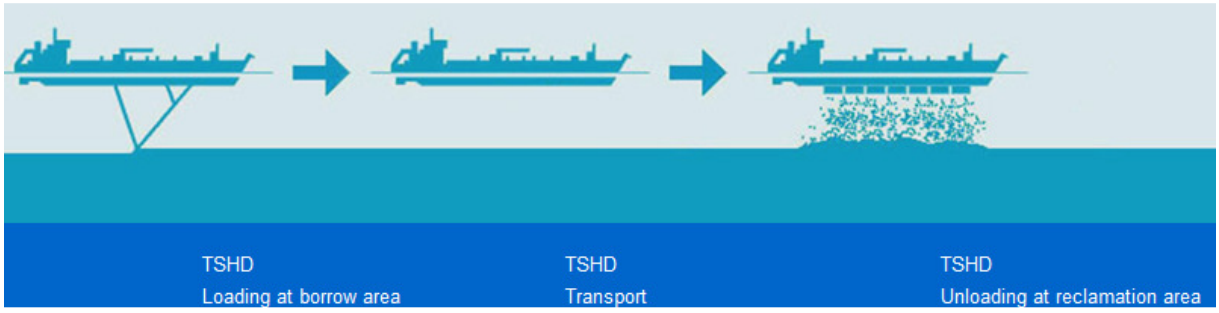

Figure 8: Dredge and dump silt by using a TSHD

Transport and deliver gravel
The double lock gravel method is a soil replacement method, for improving soil. As the name suggests, is the soil being replaced with another material. Gravel is the most used replacement material, because of its ability to give soil more stability, strength and friction.
For this project the gravel is being produced in a quarry-run, which is a production area were the gravel is produced from mountain sites or river banks. From this quarry-run the gravel has to be transported to the project site, where it can be rehandled.
For the double lock gravel the gravel has to be overloaded to a stock barge, from where it is pumped in to the ground. At the Black Sea there are just a few quarry runs, which can have the capacity to produce the gravel for the stone columns. All these quarry runs have their location far from the project site, so the gravel has to be transported by self-propelled barges. This is the only suitable option for the stone column method, the distance, weather and water conditions at the Black Sea.

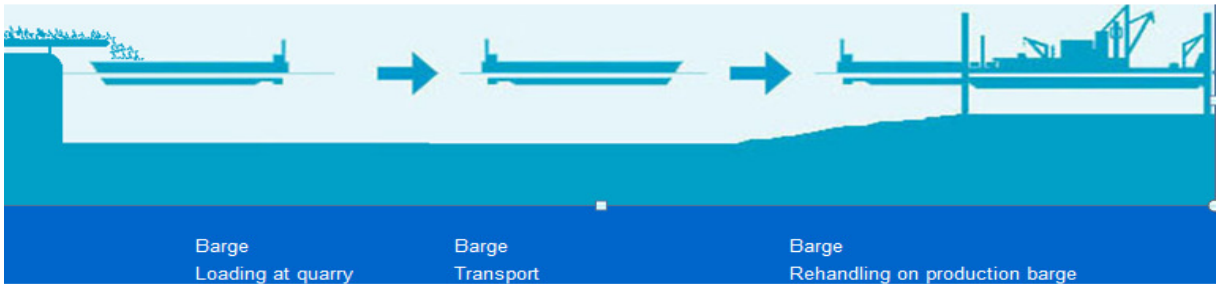

Figure 9: Transport and deliver gravel Double lock method

Production of stone columns
The technique of producing stone columns has already been described. In this paragraph the total production process for this project will be described. The stone columns have to be produced over a width of 191 meter and a length of 6 km. Since more sets will be used for the production, it is only feasible to produce the columns in horizontal cross sections. This will mean that in every cycle the columns will be produced over the production width, after which the barge is moved in the vertical direction to produce the next horizontal grid.

The grid was determined by ground mechanics, based on the data obtained from soil investigation(see ref[5]). From this data the stone column diameter and Centre to Centre (C.T.C.) distance were concluded, which led to the number of piles on a horizontal grid. The C.T.C. also led to the number of cross sections in the total length of the production area.

4.1.2 Blanket method
As stated in the above section figure 7 only shows the basic steps of the production of stone columns. Also in this paragraph the general steps will be divided in smaller steps, to get better understanding of the Blanket method.

Mobilisation/demobilisation equipment
For the blanket method the mobilisation/demobilisation process is the same as for the double lock method. The only difference is in the stone column equipment, because the used equipment is different. This does not make any difference for the process because; the quantity of equipment is almost the same.

Dredge silt
This step is completely the same as described in “dredge silt” step of the double lock gravel pump method. For a complete description of this step I have to refer to this step in the above section. In figure 10 the steps are illustrated.

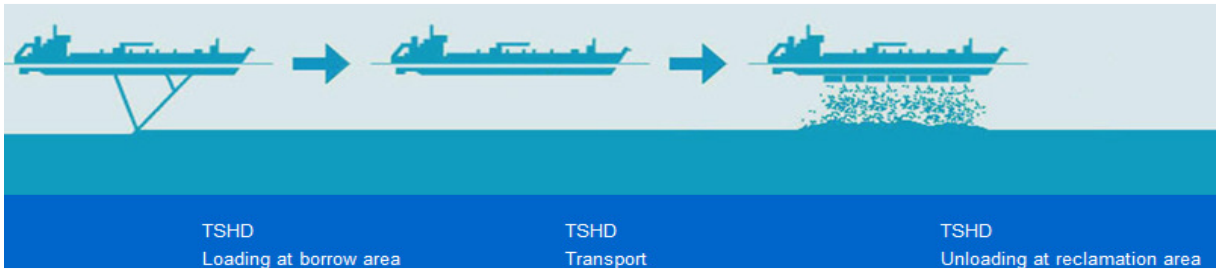

Figure 10: Dredge and dump silt by using a TSHD

Transport and deliver gravel
The Blanket method is also a soil replacement method, for improving soil. Also this method uses gravel produced in a quarry-run, which makes it the same as the double lock gravel pump method. For the blanket method the gravel has to be dumped on the seabed, from where it is vibrated in to the ground. At the Black Sea there are just a few quarry runs, which can have the capacity to produce the gravel for the stone columns. All these quarry runs have their location far from the project site, so the gravel has to be transported by a self propelled bottom door dumper. This is the only suitable option for the stone column method, the distance, the weather and water conditions at the Black Sea.

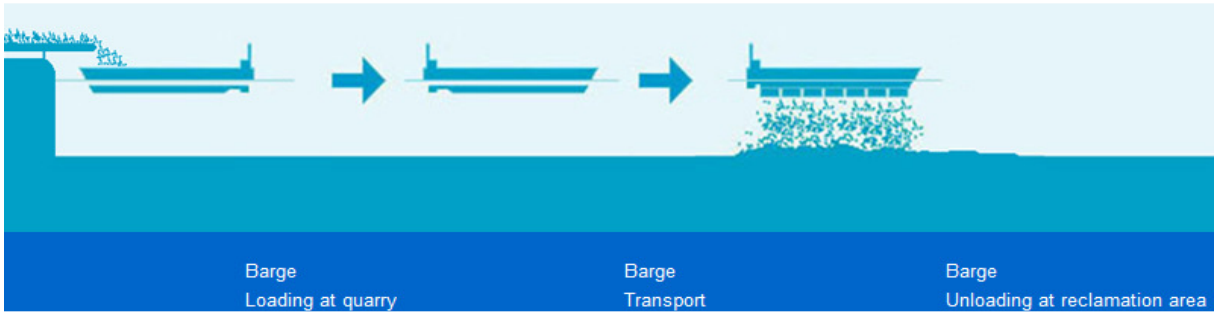

Figure 11: Transport and deliver gravel Blanket method

Production of stone columns

The total production process for this project is almost the same as described in the section of "production of stone columns" by the double lock gravel pump method. The stone columns have to be produced over the same width and length. Also the production cycle and C.T.C. distance is the same as described in the double lock gravel pump section.

The only difference of the production of stone columns by the blanket method, is the production speed. The production speed using this method, is estimated to be twice as fast as the gravel double lock gravel pump method. This estimation was made an expert and in discussion with Witteveen+Bos predicted to be reliable.

4.2 Define relations between activities

The process planning was made combining the activities and their relations. In this paragraph the activity relations will be determined, based on the gathered data. Activity relations have to be determined to be able to get better insight in the exact progress of the project.

#	Activity	Predecessors
1	Start	
2	Mobilisation dredging equipment	1
3	Mobilisation dumping equipment	1
4	Mobilisation stone column equipment	1
5	Mobilisation materials	1
6	Dredge silt	2
7	Dumping\overloading gravel	3
8	Demobilisation dredging equiptment	7
9	Demobilisatin dumping equiptment	8
10	Producing stone column grid	2,3,4,5,6,7
11	Demobilisation stone column equipment	10
12	Ready for construction	10

Table 2: Relation between activities

Table 2 led to the simple figure(see Appendix I), which is a network diagram. As can be seen in the table, almost all activities follow after one another. It was concluded that this might not be completely realistic, because some of the activities can overlap each other. Activities 6,7 and 10 could overlap each other to achieve a better planning, but this was not elaborated in the research. In

discussion with Witteveen+Bos I decided not to overlap activities, because that is only useful when delivering a final planning for the whole project.

4.3 Simplifications and assumptions

The processes of producing stone columns in the model is a simplified representations of reality. The simplifications that are made in the model are given in Appendix B. In addition to simplifying the model some assumptions are also made. These assumptions are also listed in Appendix B.

4.4 Sheets in the model and their process steps

The following section gives a description of the sheets of the Excel model and their process steps. To gain insight in the working of the model, flowcharts of the different sheets modelled in excel are included in this section. These flowcharts describe the steps every sheet of the model takes, to eventually get the required output. The different sheets in excel represent the activities described in the above section. In Appendix C screen shots of the different excel sheets are given.
The flowcharts, which are presented in Appendix D, represent every step the excel model takes to calculate the required output of the sheets, which for the active sheets are the production factor and cycle time. The output of the inactive sheets are required input data for the active sheets. In this model active sheets contain interactive calculations(calculations unified with other calculations) and inactive sheets represent data needed for these calculations.

The data input

The data input is the sheet which has to be created first after starting the excel model. The model is designed for broad utilisation, therefore first the project specific input data and production method has to be selected. The data input is the main controlling sheet in the model: it creates the main input data for all the specific activities in the production process.
The “General project data” are the data representing the specifications of the project such as size, capacity and soil conditions. The “Equipment specifications” indicate the characteristics of the equipment suitable for the project. It also represent the environmental factors, which have their influence on the equipment.

Mob/demobilisation

The mob/demobilisation is created when the model is started. It is an active sheet, which creates the mobilisation time. The attributes for this step are transport of the equipment, time for custom service and installation of the equipment. Where the “custom service time” indicates the time the equipment is docked and inspected at custom service and is checked in detail to get border clearance.

Dredging equipment

The “dredge equipment” is an inactive sheet. Its only attribute is the determination of the hopper specifications which is used by “Dredge silt” to determine their production speed and load capacity.

Dredge silt

The “Dredge silt” is an active sheet and represents the process of dredging the top soil layer at the project site. The “Dredge equipment” have a load capacity, which is a fixed number representing the maximal amount of material the hopper can load.
The attributes of this sheet are the required THSD hopper in situ capacity, process cycle time and production speed. The “Dredge silt” has a borrow area, transport and reclamation area. Which represent the process of dredging silt, transport silt and dumping the silt.

The “in situ hopper capacity” indicates the effective amount of material the hopper can carry including transport losses and the specific volume of the transport material. The “loading speed”, “sailing speed” and “dumping time” are fixed numbers indicated by the characteristics of “dredge equipment”.

Dumping/overloading gravel

The “Dumping/overloading gravel” is an active sheet and represents the process of supplying the project site with the required producing material. The “Production rate”, “Rehandling capacity”, “barge capacity”, “sailing speed”, “Sailing distance” and “Mooring time” are fixed numbers representing given equipment and quarry characteristics. Where “Mooring time” is time between the actual rehandling and the moment the barge is ready to unload.
The “Loading time”, “Sailing time”, “Rehandling time”, “Sailing distance”, the “time for Custom service” and “Cycle time” are variables which fully depend on the fixed numbers. In this sheet the “Custom service” is only modelled, when the “sailing distance” is exceeding the borders of Russia.

The attributes of this sheet are the required barge in situ capacity, process cycle time and production speed. The “Dumping/overloading gravel” has a borrow area, transport and reclamation area. This represent the process of producing material, transport material and dumping/overloading material.

Producing Stone columns

The “Producing Stone columns” is an active sheet and represents the process of producing stone columns. The “Gravel amount”, “Production dimensions”, “relocating time”, “penetrating time” and “geotextile sock” are modelled by the input data sheet. The “gravel amount” is the total amount material needed to produce the stone columns. The “production dimensions” represent required parameters needed to calculate the production speed. The “relocating time” and “Penetrating time” are fixed numbers, which represent the time to change the position of the production barge and the time to penetrate the vibroprobe to the given depth. A “Geotextile sock” is a possible option to improve the quality of the stone column and is a modelled option in the data input sheet, it represents the time needed to insert a geotextile sock after penetrating the soil.

The attributes of this sheet are the required barge process cycle time and production speed. The “Producing stone column” has a production and relocating sheet. Which represent the process of producing stone columns in a cross section and the time to relocate the barge in the length section.

Project time

The “Project time” is an active output sheet and represents the total project time for producing stone columns. The “production factors” and “Number of equipment” are input factors from the model sheet and the input data sheet, where the “number of equipment” represents the available equipment for the project. The “Actual start and finish time” is the project time plus possible lag-time or penalties. For now this is not an active element in the sheet, because it is only useful when optimising the project planning(see section 2.3).

The attribute of this sheet is the required output, namely the project time. The “Project time” is the output of all active and inactive sheets, which represent the project time in weeks.

Project costs

The “Project costs” is an active output sheet and represents the total project costs for producing stone columns. The “Actual start and finish time” is the project time plus possible lag-time or

penalty's. For now this is not an active element in the sheet, because it is only useful when optimising the project planning(see section 2.3).
The "Activity costs" are the total costs of the different activity, the "Total costs" the sum of the ""Element costs" and the "Total netto costs" the costs total costs calculated to the basic year.

The "Activity costs" are calculated in every sheet, besides the "input data " sheet, and calculates for every activity the costs/week and costs/m3. The costs/week are used in the "project costs" to calculate the total project costs and the costs/m3 are used to check the calculated total project costs. As illustrated in figure 18 the costs are divided in three groups; Equipment costs, staff costs and overhead costs. These groups are calculated from the data illustrated above it, where the "specific equipment costs" is the costs of the equipment needed for that activity(see section 2.1).

The attributes of the "project costs" sheet is the required output, namely the project costs. The "project costs" is the output of all active and inactive model sheets, which represent the project costs in euro's.

4.5 Verification and validation

Before any experiments with the described simulation model can be started, it has to be verified whether the programmed excel model actually performs the way it was intended to perform. Furthermore, it has to be validated that the excel model reflects reality. The way the excel model was verified and validated is discussed in this paragraph.

The processes of the equipment were verified by running the model manually step-by-step, to check whether the sheets correctly followed the flowcharts. Every sheet was checked on the activity's time and costs.

Furthermore, the outputs of test runs were compared with calculations based on different models available within Witteveen+Bos. There has to be noted that the Excel model of the production of the stone column techniques could not be validated, because no reference data model was available. In earlier stages of the project detailed models of the other modelled activities were required for the development of the Master plan. The outputs of the test were often a little higher than the validation values, but as discussed with experts not higher than 5%(see Appendix E). The outputs were higher because the model was designed to produce save outputs.

Besides verifying the model, there are two types of validation of interest: face-validation and statistical validation. Face-validity means that the model, at least on the surface, represents reality. Statistical validity involves a quantitative comparison between the output performance of the actual system and the model (see ref[14]).

The model could only be Face-validated, because no data of the actual process could be found. During the search for these data, it was concluded that there are no reference projects. Face-validity however, was achieved by validating model inputs and outputs with Witteveen+Bos experts.

Chapter 5 Test simulation

After the excel model has been verified and validated, the first goal to be achieved by the excel model is to produce output to compare the two stone column methods manually with the initial planning and costs estimate of experts(see ref[6] and ref[2]). The section below show the input data used for these runs, the results and conclusions.

5.1 Estimate duration of activities

The input data for estimate of the activities was first determined and then commented by Witteveen+Bos. The following methods were used to determine input values:

- A literature study was used to determine how other researchers have determined input data for similar models;
- Supplier information about the (theoretical) maximum performance of equipment was gathered;
- Where this was not available, deterministic calculations were applied, mainly based on experience of Witteveen+Bos;
- Remaining input data was assumed by the researcher, based on “engineering judgement”.

An overview of the input values can be found in Appendix E. The comments of Witteveen+Bos on these input values were incorporated in the input for the model.

5.2 Test simulation

The simulation was done using this input data. In an iterative process the numbers of sets of the equipment were manually determined for each method, starting with low numbers of equipment and adding equipment until a combination was reached, which can produce stone columns in the given time frame of the experts(see ref[2]). Next to this the total cost of both methods are compared with the estimated costs of experts(see ref[6]).

Note that the determined costs of experts are based on the given time frame, because in the project time is more valuable than costs. Next to this the estimated time and costs of the experts are based on soil improvement in general, which means it’s for both methods the same. Also note that the number of sets should only be used for comparing the methods, although they do give an indication of the actual values.

5.3 Results test simulation

First the number of sets of both methods are graphically compared in time, to determine the number of sets needed to produce the stone columns in the given time frame. Second the number of sets of both methods are graphically compared in costs.
Also the deviation of the activities in time and cost are displaced in circle diagrams. These deviations are based on the determined number of sets. The results are graphically illustrated in Appendix F.

5.3.1 Equipment in time

For both techniques the number of sets for dredging silt, dumping/overloading gravel and producing stone columns are compared with the total project duration. For the double lock gravel pump method as for the blanket method, you can see in the graph that Dumping/overloading gravel and producing stone columns are most sensitive in time. This of course because for both methods a small change in number of sets has high influence on the total project duration.
For the double lock gravel pump method you can determine from the graphic that respectively for overloading gravel and producing stone columns, 24 and 18 sets are needed to finish the total

project in the time estimated by experts. The circle diagram of project duration shows that these activities also have the biggest share in the total project duration, were producing stone columns takes most time with a share of 58%.

When using the Blanket method the graphic shows that the same number of sets for Dumping gravel is needed as for overloading gravel using the double lock gravel method, namely 24 sets. The difference in both methods is that when using the blanket method, less number of sets are needed for producing Stone columns, namely 17 sets.
The same as by the double lock gravel pump method, the production of stone columns and dumping gravel has the biggest share in the total project duration. The only difference with the other technique is that dumping gravel takes less time than overloading gravel. As you can see in both circle diagrams, dumping gravel has a smaller share in the total project duration, which indicates that it takes less time than overloading gravel.

5.3.2 Equipment in costs

Also for equipment in costs the number of sets for dredging silt, dumping/overloading and producing stone columns are compared with the total project costs. In both graphics of equipment in costs there can be seen that the estimated costs of experts is far higher than the costs generated by the model for the activities.
For the double lock gravel pump method as well as for the Blanket method the results are financially pretty similar. For both methods dredging silt is most sensitive in costs, because a small change in number of sets means high changes in the total project costs. Next to this for both techniques producing stone columns and dumping/overloading gravel have the most influence on the total costs, because they have the biggest share in the circle diagram of total project costs. The only difference is that the share of dumping/overloading gravel for the Blanket method is much larger than for the double lock gravel pump method. This can easily be explained by the fact that for the blanket method much more gravel is needed, which of course mean higher total costs for that activity and therefore a bigger share in the total project costs.

5.4 Conclusion

Based on the results of the comparative simulation runs and the graphical results in appendix F, the following conclusions are drawn:

Conclusion 1: The number of sets of the activities can only be determined by the equipment in time.
As described and shown in the graphics of the equipment in time. The estimated costs for both techniques are far higher than the output data of the excel model. As can be see none of the activities line's interact with the estimated costs, so based on cost it's not possible to determine the number of equipment needed. As can be seen in the equipment in time graphics the estimated time of experts interacts with every of the activities, so based on these graphics a good estimation of the needed equipment can be made.

Conclusion 2: For both methods the number of sets for producing stone columns and dumping/overloading gravel are most sensitive in time.
As described and shown in the graphics of the equipment in time. A little change in number of equipment of the activities, producing stone columns and dumping/overloading gravel, have a large influence on the total project time, so these activities are highly sensitive in time.

Conclusion 3: For both methods the number of sets for dredging silt is most sensitive in cost.
As described and shown in the graphics of the equipment in costs. This is the same as conclusion 2, because the graphics show that a small change in number of equipment largely influence the total project costs. The other activities, producing stone columns and dumping/overloading gravel, both have a fairly straight line, which indicates little sensitivity in total project costs.

Conclusion 4: Overloading gravel takes relatively more time, but does relatively cost less.
As described and shown in the graphics of the equipment in time and costs and also the circle diagrams of project duration and costs. The graphics show that overloading gravel takes relatively more time than dumping gravel, because overloading gravel in terms of percentage takes 3% more time than dumping gravel. In the circle diagram of costs can be seen that overloading gravel is more than 15% less expensive than dumping gravel, which means that overloading gravel is relatively less expensive in use.

Conclusion 5: The initial time frame of experts is theoretically feasible, only practically unrealisable.
The graphics of the equipment in time illustrated that it is possible to improve the soil in around 80 weeks, but the number of sets for producing stone columns is practically not possible. For respectively the double lock method and the blanket method the required number of sets are 23 and 17. First of all not that many sets are globally available, but more important experts state that's impossible to use that many number of sets in the area given for soil improvement.

Chapter 6 Risk identification

During the duration of the project a lot of factors can change with respect to planning and costs. The custom service can last longer, pricing of materials can increase and the available equipment can fluctuate. All kind of these changes form a risk for the duration and the costs of the project.

In this section the main uncertainties are identified and described, because as described by Al-jibouri(see ref[12]) first the risks have to be identified before they can be analysed. First a list of possible uncertainties was established using a literature study, an internet search and by consulting experts. From this list the main uncertainties were selected by experts, based on earlier expertise and results of a test run with Crystal ball(see appendix G). The impact of these fifteen important uncertainties are analysed in the following sections using the software parcel Crystal ball.

The program Crystal ball is able to analyse these uncertainties, based on separate distribution. For that reason this section describes the risks and their distribution. Before these risks will described they will be categorised.

6.1 Risk categories

Several uncertainties hide in the complete life cycle of producing stone columns. By identifying these in advance it is better possible to take them into account, anticipate and to react as certain risks occur. In this research two outputs are taken in to account; project time and project costs. These outputs are analysed on two methods, namely “Double Lock Gravel Pump” method and “Blanket” method.

The identified uncertainties change the input variables of the Excel model, what allows them to influence the output variables(e.g. project costs and time). Table 3 shows an overview of all the main uncertainties and the output it has it influence on.

Uncertainties	DLGP method costs	Bl. method costs	DLGP method time	Bl. method time
Stone Column length	x	x	x	x
C.T.C. distance	x	x	x	x
Custom service dumping equipment	x	x	x	x
Custom service Stone Column equipment	x	x	x	x
Custom service THSD	x	x	x	x
Stone Column diameter	x	x	x	x
EF gravel production				x
Fuelprice	x	x		
Gravelprice	x	x		
Length production area	x	x	x	x
Number of sets Blanket Method		x		x
Number of sets Double Lock Method	x		x	
Number of sets Dumping equipment	x	x	x	x
Number of sets THSD	x	x		
Production rate quarry			x	x
Productionspeed Blanket Method		x		x

Productionspeed Double Lock Method	x		x	
Relocating time			x	x
Sailing distance dumping equipment	x	x	x	x
Wavedelay factor	x	x	x	x
Winddelayfactor			x	x
Total	**15**	**15**	**15**	**16**

Table 3: Main uncertainties and their influence on the outputs

6.2 Risk description and distributions

To be able to analyse the impact of uncertainties with Crystal ball for each uncertainty a distribution was made. This distribution replaces fixed values by variable values. In this research all the distributions are triangular, because experts expertise and literature could best estimate minimal and maximal values of the uncertainties.

In section 7 these distributions are used in the Monte Carlo simulation carried out to get an idea of the probable project outcome and reliability of these outcomes. The graphical distributions are displaced in Appendix H.

6.2.1 Distribution stone column length

The stone column length is the length of the gravel pile, from bottom to the top soil layer. Since there is few data about the soil conditions at the project area, it is really hard to determine the needed depth of the stone column. If the soil conditions are better as expected the stone columns length could be less and it would be the other way around if the soil conditions are much worse. This means that the stone columns could be very long or very short, for this reason the min. and max. value was determined by the restriction of the technique(see ref.[14]). As the graphic illustrates the min. value are 15 meter and the max. is 25 meter.

6.2.2 Distribution of C.T.C distance

The C.T.C. distance, is the Centre To Centre distance between the stone columns. This an uncertainty, because there is as mentioned limited information about the soil conditions at the project area. The soil conditions stipulate the C.T.C. distance directly, because it has direct influence on the degree of soil improvement. Also for this distribution the min. and max. values are determined by the restriction of the technique(see ref.[14]). As the graphic illustrates the min. and min. value are respectively 1.5 meter and 2.5 meter.

6.2.3 Distribution Custom service

The custom service cover three components: dumping equipment, dredging silt equipment and stone column equipment. The time for border crossing can fluctuate, due to bad weather conditions, longer waiting times at custom service and delays in border clearance. It is hard to make a good estimation of the time needed for Custom service, because experts state that the Russian border is hard to cross. For this reason the min. and max. value of Custom clearance are estimated at 0.5 days and 364 days, because these are the legal min. and max. restrictions at custom service in Russia.

6.2.4 Distribution of stone columns diameter

The stone columns diameter is as the name suggests the diameter of gravel pile for soil improvement. Like a lot of the ground mechanical parameters of the model, this uncertainty also has its direct background in the soil parameters of the Black Sea's ground. As mentioned earlier there are very little soil parameters available for this project. For this uncertainty the min. and max. value are concluded from ground mechanical restrictions of producing stone columns. As illustrated in the graphic these values are 0.70 meter and 1.10 meter.

6.2.5 Distribution of Effective Factor gravel production

This uncertainty is only used for the blanket method, because for this method first a gravel blanket has to be dumped. The "EF gravel production" is the factor, which indicates how many extra gravel there has to be dumped in the blanket. This factor is determined by experts, but they cannot agree on the height of this factor. For this reason the min. and max. value are determined from the expertise of experts. The likeliest value is the value, which most of the experts stated as the best factor. The min. and max. value are determined by the lowest and highest mentioned factor.

6.2.6 Distribution of gravel and fuel price

For large projects in civil engineering unit prices are hard to estimate, because prices can fluctuate a lot in 4 to 5 years. So it is difficult to give a good estimate of the fuel and gravel price, which makes these prices a uncertainty. As said it is difficult to give a reliable estimate, for this reason the prices of the past ten years are compared to determine a min., max. and likeliest value. These values are illustrated for the fuel and gravel price in graphics of Appendix H and are indicated in euro's.

6.2.7 Distribution of length of production area

The stone columns as described have to be produced under a large part the breakwaters. The width of this area is given by the breakwaters construction, but the length of the area this area can still fluctuate. This is caused by the earlier mentioned lake on soil parameters. The soil parameters are directly connected to the production length of the stone columns. In this case a triangular distribution was used, because the min. and max. value could be determined from the 3D model produced by experts. The likeliest value is determined by discussing it with experts of Witteveen+Bos and are indicated in kilometres.

6.2.8 Distribution of number of sets equipment

For large scale projects like this project a lot of equipment is needed in every stage of the process, which is the problem by producing stone columns. The problem is that it is difficult to make a good estimate of the available equipment and also how many equipment is needed. This last uncertainty is the biggest problem for this project, because it has to be finished in time but it also has costs restrictions. For the distribution the availability of equipment was used, because this can be determined from experts. The figures 38-40 illustrate the distribution of equipment needed for the different activities in producing stone columns.

6.2.9 Distribution of production rate quarry and sailing distance

For the project a lot of gravel and sand is needed, which is produced in a so called production quarry. This quarry is most of the time a mountain, which is being exploded to produce the materials. The problem for this project is the amount of materials needed, which makes it hard to find a suitable quarry. In this stage of the project it is not determined yet which quarry is used, so this is a big uncertainty. This uncertainty reflects in the production rate of the quarry and sailing distance to the quarry, which is illustrated in graphic. For these distributions the values are determined by data available for the quarry's near the Black Sea and are indicated in m3 gravel/hour and in kilometres.

6.2.10 Distribution of production speed stone column technique

Producing stone columns is a specific job, which only can be done by very few companies in the world. Therefore not that much information is available for students or experts within Witteveen+Bos, which makes it hard to estimate production rates of the both stone column methods. The production rates of the methods are therefore uncertainties. The values of the distributions illustrated in graphics are estimations of experts and are indicated in m3 gravel/hour.

6.2.11 Distribution of relocating time

As described in chapter 2 the production barge of stone columns has to be relocated during the process, which takes time. A lot of factors can influence this relocating time, which makes it an uncertainty. Experts estimated that it would take two hours in normal conditions, but it could also be shorter or longer when for example the weather changes. In the distribution the min. and max. values are determined by experts of a dredging company, which often relocate barges for other purposes than producing stone columns. The values are indicated in hours.

6.2.12 Distribution of wave/wind delay factor

The stone columns have to be produced in the Black Sea, which makes it possible for wind and waves to interfere in the production process. For every activity of the production wind and waves can have their influence on the process, but because it is caused by nature it is hard to make good assumptions about its effect. Due to this the effect of wind and waves are an uncertainty. In the distributions it is indicated in percentage delay time. The values are based on assumptions made for the climate at the Black Sea.

Chapter 7 Risk analyses

The uncertainties and their distributions of chapter 4 are used in a Monte Carlo simulation to test the impact of these variables on time and cost feasibility of this project. This chapter will discuss firstly the method of Monte Carlo simulations and the simulation program Crystal Ball. Afterwards the impact of the uncertainties on the time and cost feasibility will be analysed using the two indicators, which have been already rather used; Total project time and costs.

7.1 Monte Carlo simulation

In the program Excel the project planning and financial result dependent of several input parameters have been made. Instead of giving fixed values these parameters have a distribution in Crystal ball as described in chapter 3. By simulating several values from the distributions of the input parameters and filling them in the Excel model, different output values are generated. After generating these distributions of the input parameters 10.000 times, a distribution of the output parameters is generated. These output distributions can be used in the risk analyses, because from these distributions the likeliest, minimal and maximal values can be determined(see ref[12])

7.2 Risk analyses

A risk has phases, namely the first phase which contains the appearance of a negative change on the project result. The second phase is the effect which this change has on the project results(see ref[12]). The chance of a negative chance has already been described in chapter 4. First the impact of these changes on the project results will be described and illustrated in this section. The impact will be described for both stone column methods using the two output parameters: Total project time and costs. Note that the uncertainties in the graphics correlate with each other and that only the position can chance and not the bandwidth, if the basic value changes the whole graphic shifts. Second the uncertainties will be analysed using a sensitivity analysis. Note that in Appendix F all the data for the illustrations are given.

7.2.1 Double lock gravel pump method

As illustrated in figure 12 the basic situation, which means that all the parameters have their likeliest value, is 249 weeks. For the total project time only the C.T.C. distance has a big chance of extending the total project time. The stone columns diameter, length of production area and the number of sets for producing stone columns have a good chance of shortening the total project time. When all the uncertainties are taken into account the project will most likely(90% reliable) be finished in 223 weeks, which is shorter than the basic situation(249 weeks).

The total project cost are also analysed and illustrated in figure 13. In the basic situation the project costs are 288 million euro. As illustrated in the figure there are just a few uncertainties, which have a great influence on the total project costs. Only the custom service of dumping and stone column equipment, the C.T.C. distance and the stone column diameter can influence the total project costs. If for the total project costs all the uncertainties are taken into account these costs will most likely (90% reliability) be higher than expected, which will be around 487 million.

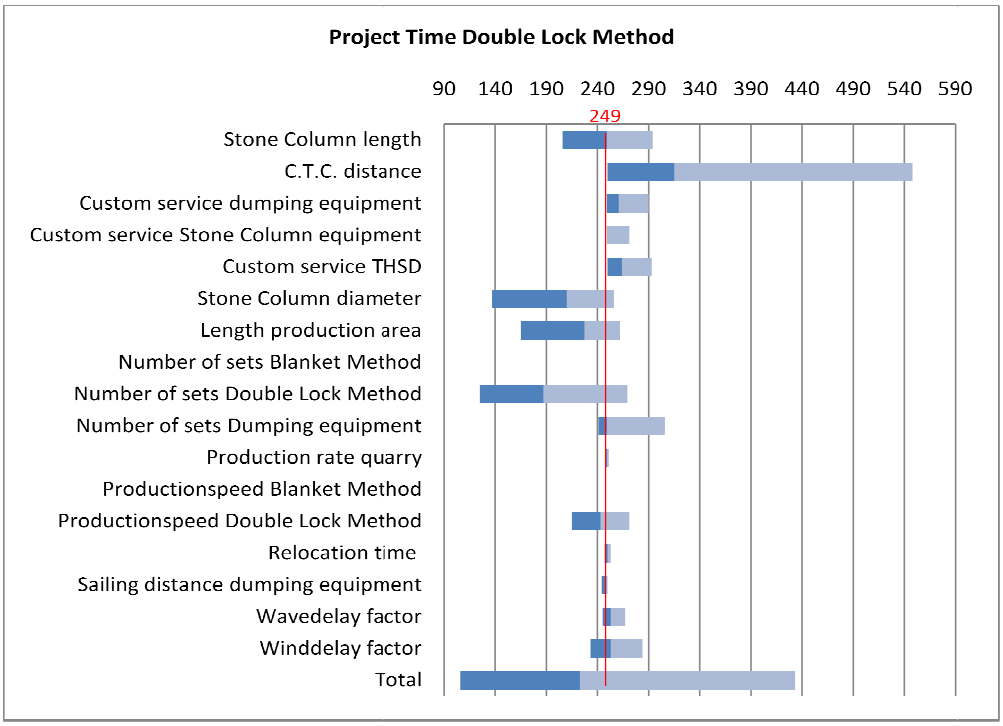

Figure 12: Results Crystal ball: Total project time for the Double lock method

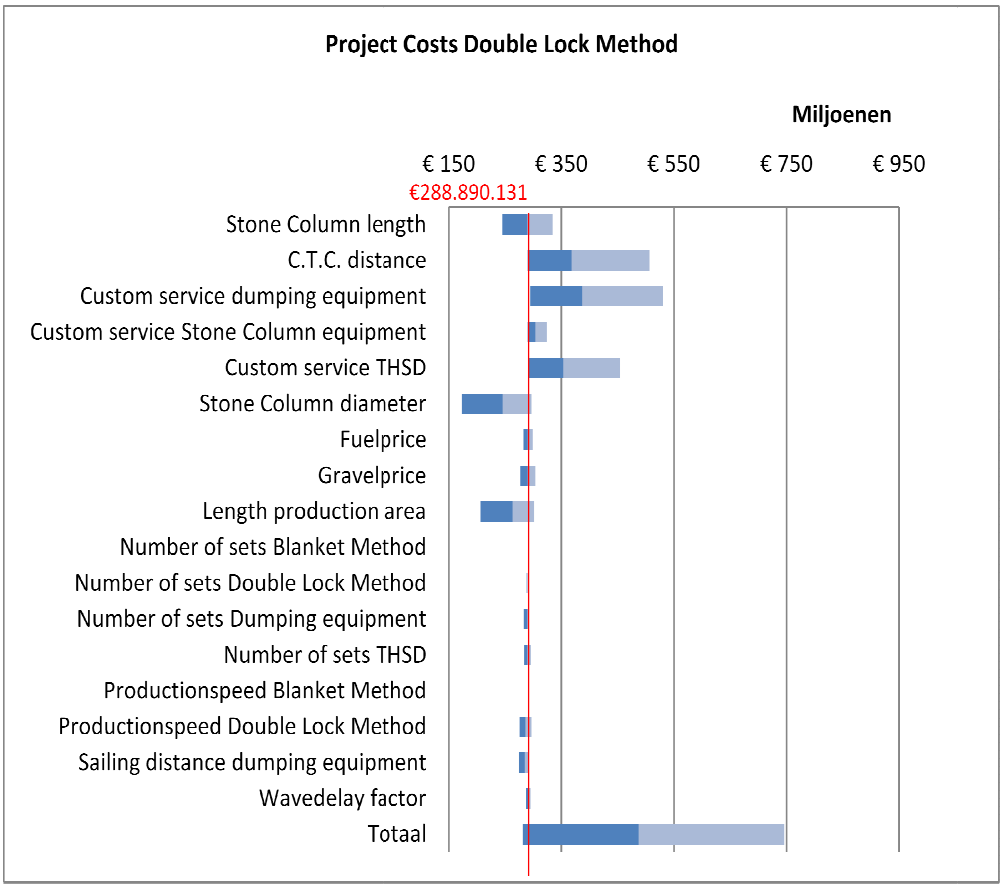

Figure 13: Results Crystal ball: Total project costs for the Double lock method

7.2.2 Blanket method

Also the Blanket method is analysed on the total project time and costs. The results of this analysis is illustrated in figure 14 and 15, where the redline is for both figures the basic situation. The same as with the Double lock method, the C.T.C. distance is uncertainty with the biggest influence on the total project time. If all the uncertainties are taken into account the total project time will be a little shorter than the basic situation. It would take 185 weeks to finish the total project.

As illustrated in figure 15 the total project costs are in the basic situation around the 285 million euro's and again there are just a few uncertainties which influence the output heavily. These are the same factors as for the Double lock method and also for the Blanket method the total project costs will most likely(90% reliable) be higher as expected, which is 475 million instead of 285 million.

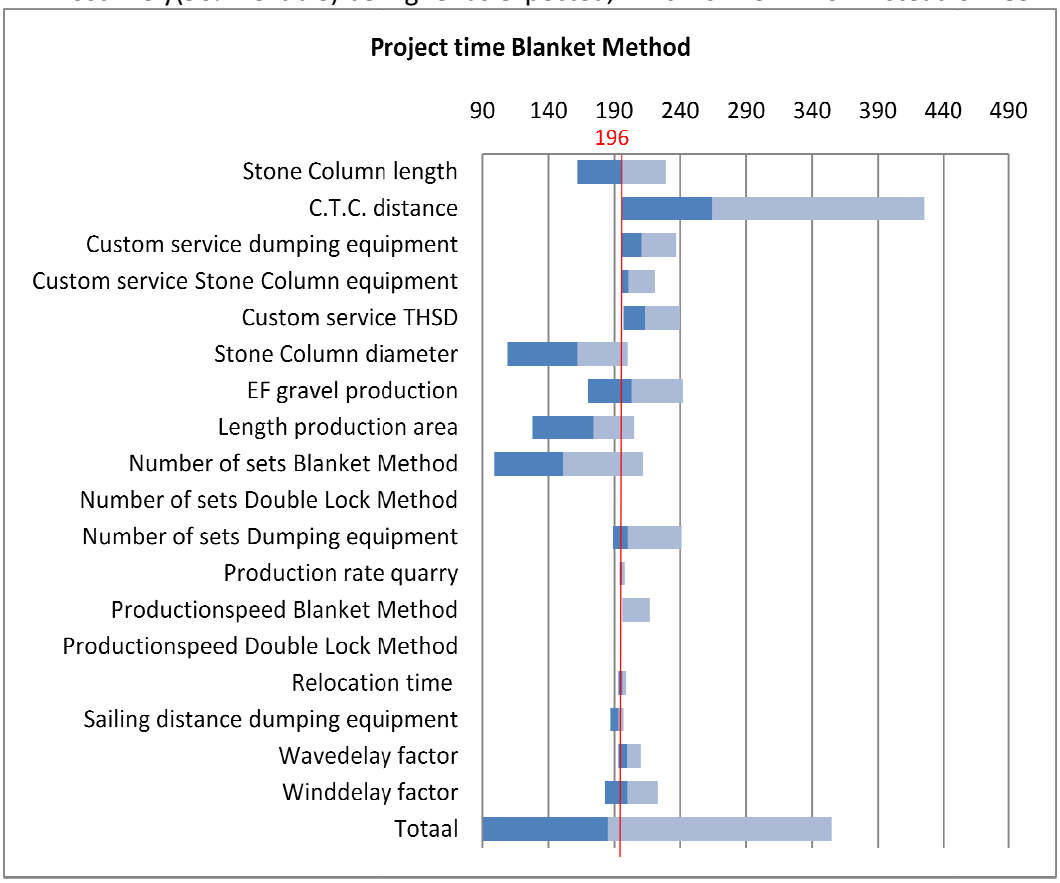

Figure 14: Results Crystal ball: Total project time for the Blanket method

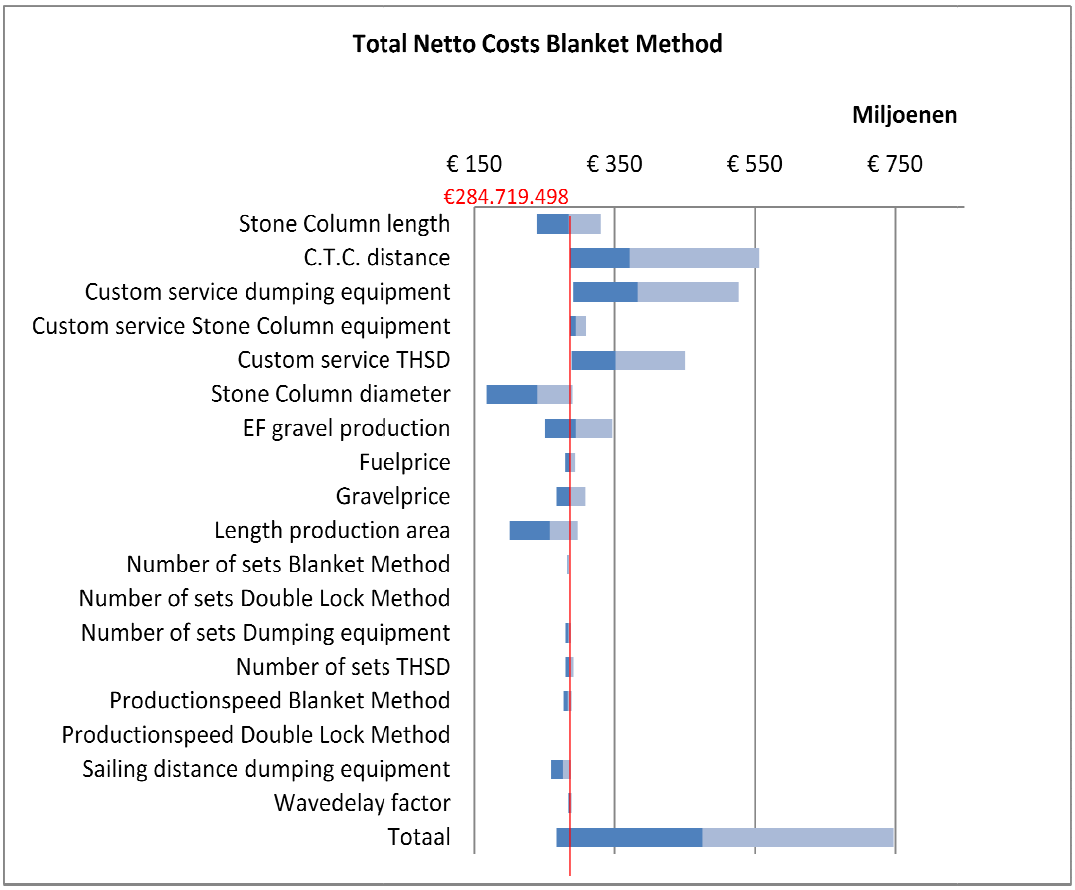

Figure 15: Results Crystal ball: Total project time for the Blanket method

7.3 Sensitivity analysis

In the past section the impact of the uncertainties are analysed, in this section the influence in terms of percentage of each risk variable and how this influence the project result. All the variables are manually changed with different percentages and the difference these percentages have on the project outcomes are illustrated graphically. In this analysis the project outcomes are the total project time and costs.

7.3.1 Double lock gravel pump method

In figure 16 and 17 the results of the sensitivity analysis for the double lock method are illustrated. For the total project time there are six uncertainties which have a sensitivity for the total project time, which means that a small chance has large influence on the project result. For the double lock method the column diameter, C.T.C. distance, length of production area, production speed, number of sets and stone column length are highly sensitive. Especially the column diameter and C.T.C. distance can have influence on the project results. When the C.T.C. is decreased with 20% it can increase the total project time with 132 weeks and when the column diameter is decreased with 20% it can decrease the total project time with 85 weeks.

As illustrated in figure 17 there are only four uncertainties, which are sensitive for the total project costs: the column diameter, the length of the production area, the stone column length and the C.T.C. distance. Where again the column diameter and C.T.C. distance are the most sensitive for chances.

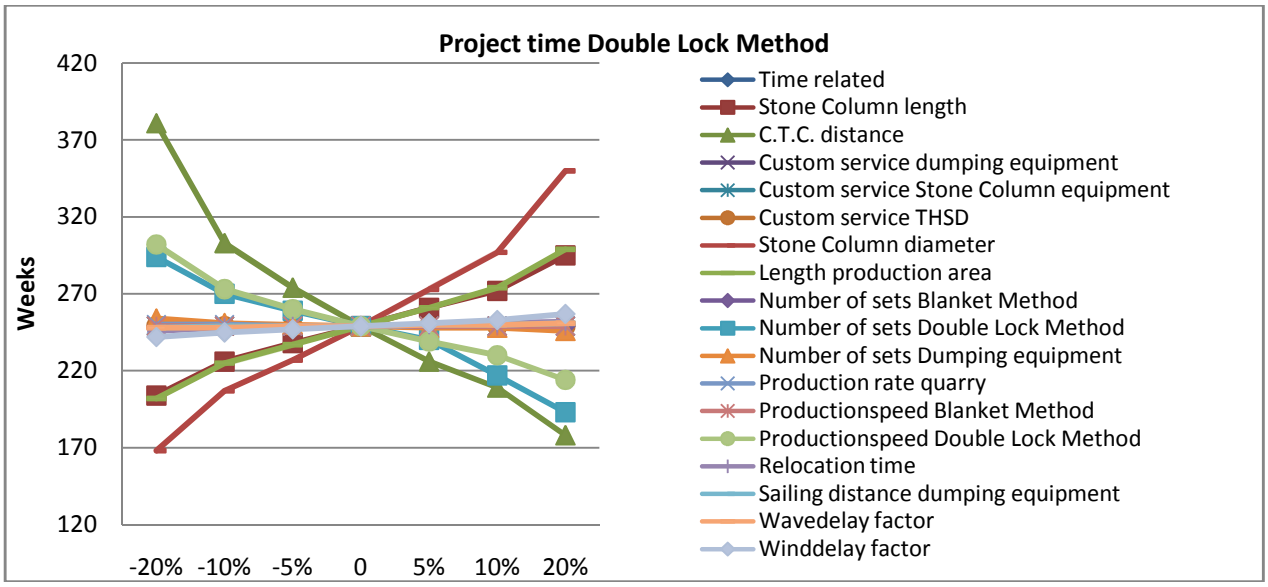

Figure 16: Sensitivity of total project time for the double lock method

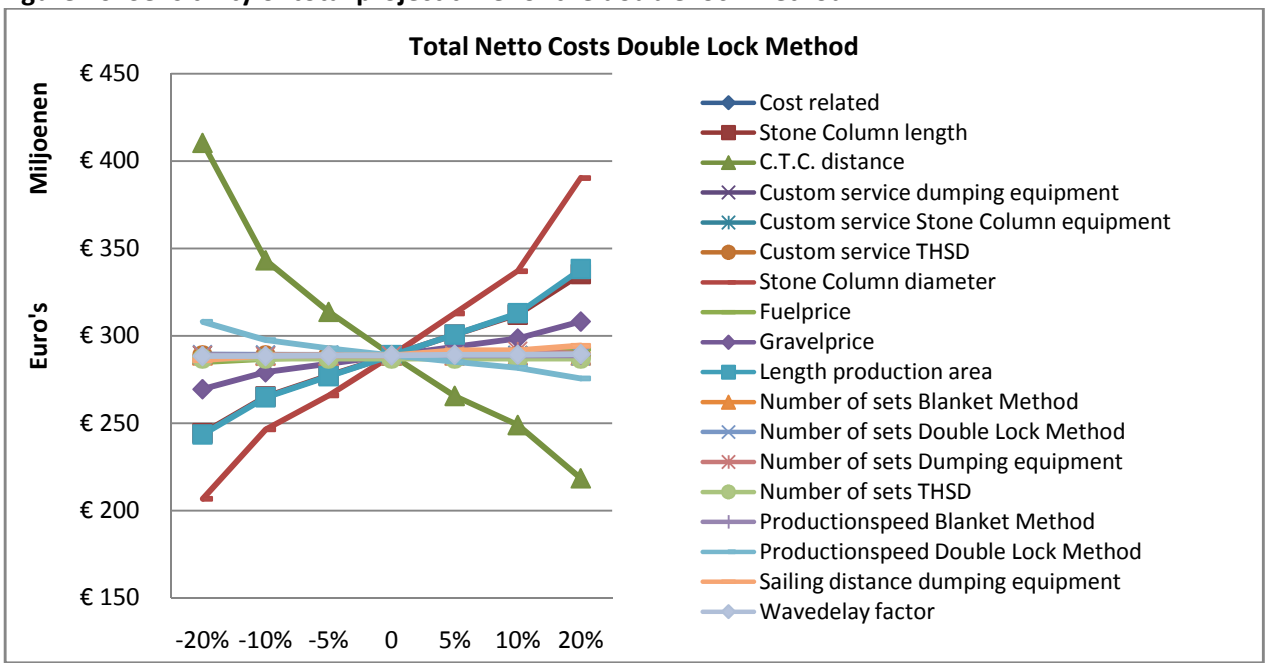

Figure 17: Sensitivity of total project costs for the double lock method

7.3.2 Blanket method

For the Blanket method also a sensitivity analysis was done for the project results. The sensitivity chart is pretty similar to the chart illustrated in figure 16, only in this case a seventh uncertainty is highly sensitive. The EF factor of the gravel blanket is also highly sensitive in the Blanket method, but again the column diameter and C.T.C. distance are most sensitive for total project time.

Also the sensitivity chart of the total project costs is very similar as the chart of the double lock method, but also in this case the EF factor of the gravel blanket is a highly sensitive. Next to this the gravel price is also more sensitive for total project costs for the blanket method, as for the double lock method. Unchanged is the fact that the C.T.C. distance and column diameter are also for the blanket method the two most sensitive uncertainties.

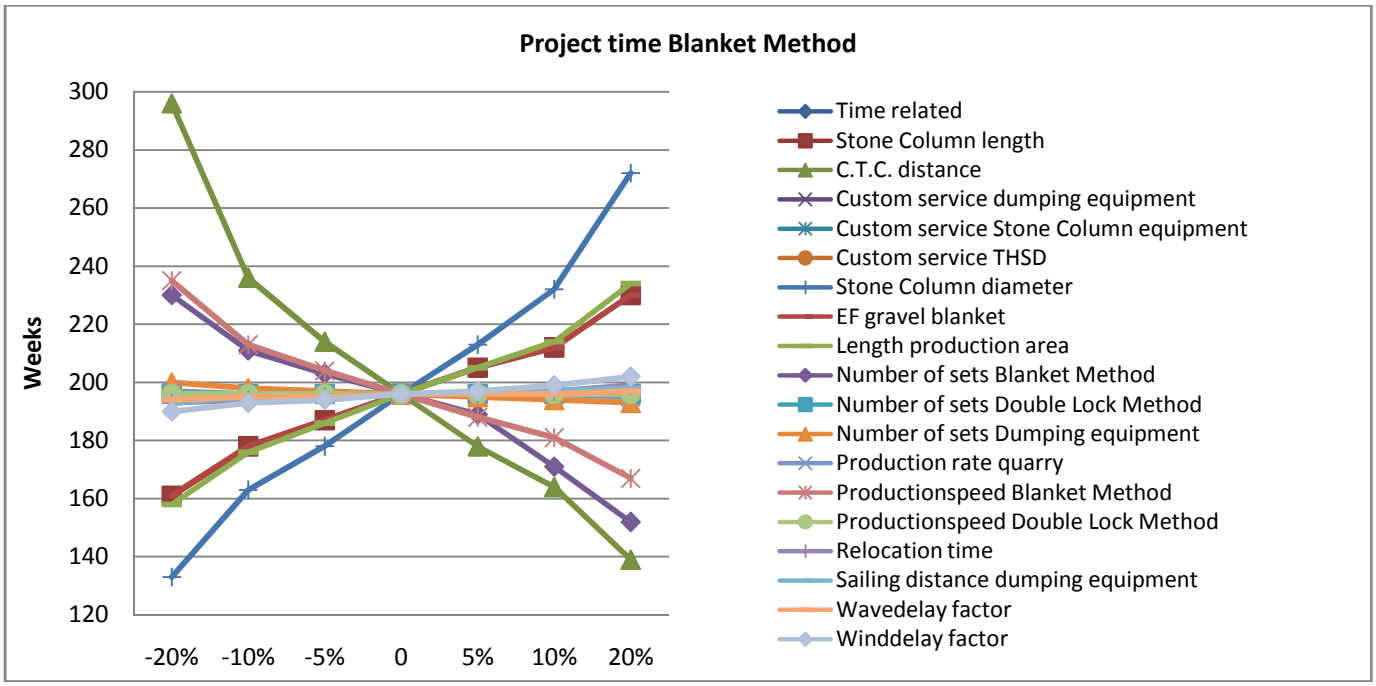

Figure 18: Sensitivity of total project time for the Blanket method

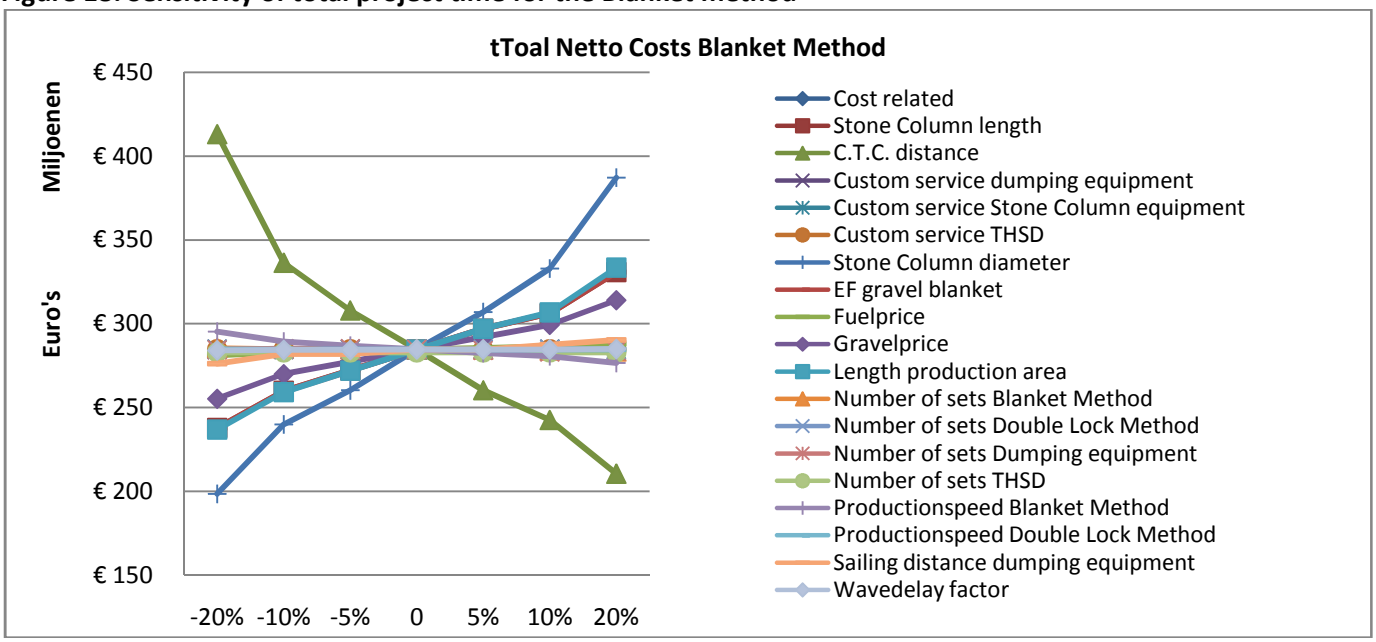

Figure 19: Sensitivity of total project costs for the Blanket method

Chapter 8 Conclusion and recommendation

This research set out to evaluate the stone column technique and its producing methods. Furthermore, the total project time and costs are estimated and analysed. This chapter will discuss the conclusions of this research. First the conclusions are drawn, after which recommendations for the future of the project are made.

8.1 Conclusion

To determine the project results(Total project time and costs), a Excel model was developed. The model was first used to determine if the initial planning and cost estimate of the experts could be correct. These simulation runs led to the following conclusions(see section 3.3):

-The number of sets of the activities can only be determined by the equipment in time
-For both methods the number of sets for producing stone columns and /overloading gravel are most sensitive in time
- For both methods the number of sets for dredging silt is most sensitive in cost
-Overloading gravel takes relatively more time, but does relatively cost less
- The initial time frame of experts is theoretically feasible, only practically unrealisable

Based on these conclusions the model was further used without the initial time and costs estimate of experts. The number of sets for every resource was used in the detailed simulation and sensitivity analysis were the ones suggested by experts and discussed with Witteveen+Bos.

Risk analysis

For the detailed analyse the program Crystal ball used a Monte Carlo simulation to determine the effects of uncertainties, which led to the following conclusions.

-For both stone column methods only the C.T.C. distance can influence the total project time negative
-Also for both methods the Stone column diameter, the length of the production area and the number of sets for producing stone columns can influence the total project time more positive
-The total project time will be lower as expected, when all the uncertainties are taken into account
-For both stone column methods the custom service and C.T.C. distance can influence the total project costs negative
-Also for both methods the length of the production area and stone column diameter can influence the total project costs more positive
-The total project costs will be higher as expected, when all the uncertainties are taken into account

Sensitivity analysis

A sensitivity analysis on the input data was then performed for the two selected stone column methods and their project results. From this analyse the most influential uncertainties were determined for total project time and costs. For both production methods these uncertainties were almost the same. The most influential uncertainties for time:

-C.T.C. distance
-Stone column diameter
-Length of production area
-Stone column lengths
-EF gravel blanket(only for Blanket method)
-Production speed for producing stone columns
-Number of sets for producing stone columns

The most influential uncertainties for costs:

-C.T.C. distance
-Length production area
-Stone column diameter
-Stone column length
-EF gravel blanket(only Blanket method)
-Gravelprice(only Blanket method)

From the sensitivity analyse it can be concluded that especially the uncertainties connected to the lack of soil parameters have high influence on the project results. The C.T.C. distance, length of production area, the stone column length and the stone column can directly be connected to soil properties. Next to the lack of information about production values for producing stone columns is also a important uncertainty, because the activity of producing is important in the critical time path.

8.2 Recommendations

The goal of this research was not to give a definitive answer to which method is preferable, or if the soil improvement using the stone column technique is usable. Below recommendations for the project are made, which can help to predict the feasibility of using the stone column technique in the future of this project.

Perform a complete and accurate soil investigation

The soil investigation on which the most important uncertainties are based on is not accurate. For that reason a lot of assumptions were made for the soil properties, which led to very low quality estimated soil parameters. In this research it was concluded that the most import uncertainties are directly connected to these soil parameters, which led to variable project results. As illustrated in figure 52 to 55 the C.T.C. distance and stone column diameter are the two most sensitive uncertainties for total project time as well as for total project costs. For example a lower C.T.C. distance can possibly lead to a cost reduction of almost 75 million and a time reduction of more than 50 weeks(see figure 54 and 55).

Obtain better information and more accurate information of stone column production

The production values of producing stone columns are in this research based on estimate of experts, but because very little information is available about producing stone columns these values could be incorrect. As concluded in the risk analysis and sensitivity analysis these values are important for making an accurate estimate of the total project time and costs, so if the cost and time estimate has to be more accurate in the future it is recommended to test the used production values of this research.

Assess the original project planning on feasibility

In section 3 it was concluded that the original time frame of around 80 weeks for producing stone columns is not feasible, which can also be concluded from the more detailed analysis in section 5. As illustrated in figure 52 to 55 it is also not possible to produce the stone columns in the original time if the most positive values are used in the calculation. So for this reason it is important to assess the original project planning, because the likeliest given time frame for producing stone columns is minimal around 200 weeks(see figure 48 and 50). This means that the gap between the original time frame and the most likely time frame is large, which can influence the next stage in the project planning.

Research the possibilities to use more sets of equipment during the production of stone columns

From this research there has to be concluded that it is not feasible to produce the stone columns in the given time frame. As recommended above it is needed to get accurate soil parameters, but as stated in section 3 it is also possible to reduce the total project time by using more sets of equipment for the production of stone columns. Experts concluded that it is practically not desirable to use more than 15 sets of equipment, but this is concluded out of expertise and not of an accurate research. This research concluded that more sets of equipment directly lead to lower total project time, so if possible it is a functional way of lowering the time needed for soil improvement.

Chapter 9 Reference list

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3. Deliverable 2.6: solutions for options of soft soil compacting or replacement, Project (TEO) of «Federation Island», and breakwater constructions, Witteveen+Bos, June 6, 2008

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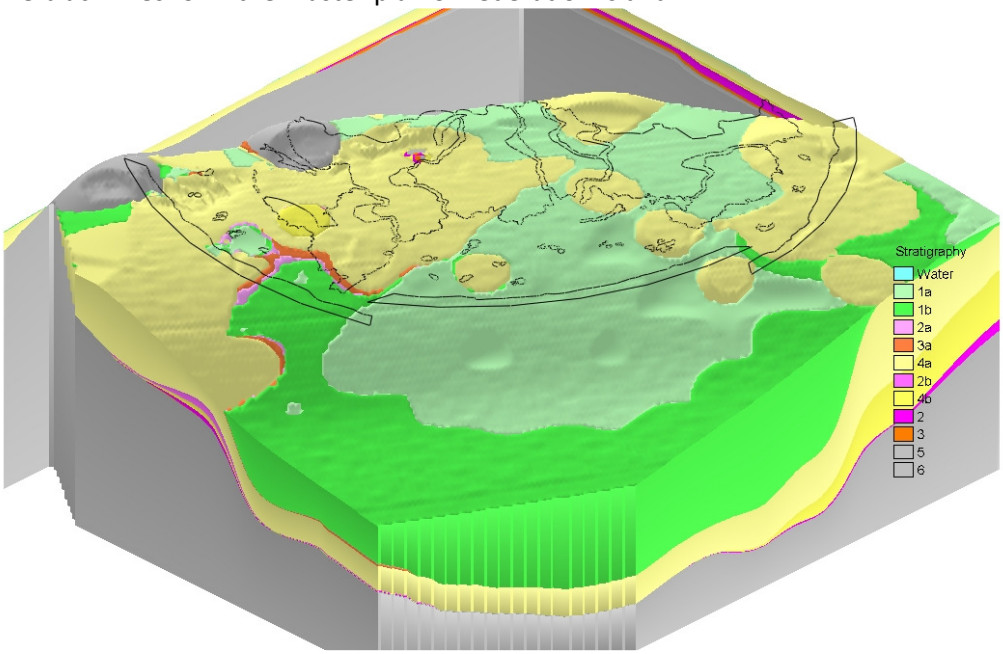
9.1 Websites

http://www.dredgers.nl/
Portal for dredge equipment
http://www.ub.utwente.nl
Portal for literature

Appendix A: Three-dimensional soil model

In this appendix the three dimensional model and a short description of the ground layers is included. This model is the visualisation of the soil investigation, which was made for M-industry. The black lines form the master plan of Federation Island.



Soil layer 1a: sandy-loamy silt

Only tests on unit weight and Atterbergs limits are available. These tests show a volumetric weight of approximately 18 kN/m³ with a natural water content of 34 %.

The Plasticity Index is very low: 8, which indicates a non plastic soil. Determination of the liquid limit by rolling will probably not be possible on this soil type. Based on field interpretation the soil is indicated as Silt. This may be interpreted as silt fraction (grains smaller than 0.1 mm) or silt deposit (muck, slurry).

The organic content is 1 %.

Based on present information on consistency the following soft soil types maybe present:
soft clay;
silt (granular material with grain size between 5 and 100 µm);
muck.

The high volume weight does not correspond with the bad consistency. Low organic content does not indicate muck. The soil type is most probably silt (grains smaller than 0.1 mm) with low clay content. Grain size distribution of river deposit (ref[2]) confirms this assumption. Clay content is most probably smaller than 15 %.

The following additional information is required to confirm the soil type:
information on mineralogical composition (distinguish silt and clay);
microscopic photographs (optional for grain size and shape silty material);
grain size distribution curves based on hydrometer test for grains smaller than 0.1 mm (distinguish silt and clay);
CPT for determination consistency and/or relative density.

For engineering purposes the following additional parameters shall be determined:
strength parameters Cu (clay) and/or drained parameters phi and c (clay and silt). preferably by CU triaxial test;
compressibility preferably Anglo-Saxon method (alternative Eoed);
coefficient of consolidation;
all test to be applied on undisturbed samples.

Soil layer 1b: loamy silt
For layer 1b more information is available. The soil is described as loamy silt. Distinction is based on visual judgement during survey.

The clay fraction for 1b is probably higher than for 1a, which results in higher Plasticity Index of 14%. Due to the sampling method it is apparently possible to make samples for laboratory test as opposed to soil type 1a.

Organic content is little bit higher for soil type 1b, but still relatively low (2.5 %)

The weight is approximately 18 kN/m³. The determined strength parameters show large spread. The testing method is probably direct shear test. For comparison of strength parameter results Cu rather shall be compared and analysed in stead of c and phi. Combination of c and phi at stress level of probable stress level of 100 kPa results in Cu which ranges between 20 and 40 kPa for 100 kPa stress level.

The average Cu based on available samples is 28 kPa. Drained parameters for this material are estimated effective parameters c'= 2 and phi = 15. These strength parameters are very low and will lead to stability problems of the embankments without additional measures.

Soil layer 2
Layer 2 is indicated as sandy loam. The soil is slightly plastic. The organic content is not determined.

The water content of saturated sample is very low (22 %). Volumetric weight is relatively high:
20 kN/m3.

The determined Eoed is 6,000 kPa. The Strength parameters are considerably better than soil layers 1a and 1b. The lowest strength parameters determined are c=14 kPa and phi=30o.

Other soil layers
The soil layers 3 to 5 are soil layers with high strengths and low compressibility as compared to the soil layers 1a and 1b. Layer 3 is a hard clayey loam with high CU of minimum 50 kPa. Layer 4 and 4b are fine sands (milky sands) with fine content (grain size <0.1 mm) of 40 %.

Layer 5 is a clayey loam with CU of 100 kPa. Finally layer 6 is described as Argillite of low strength softened which is bed rock with Uni-axial compression strength (UCS) of average 1 MPa.

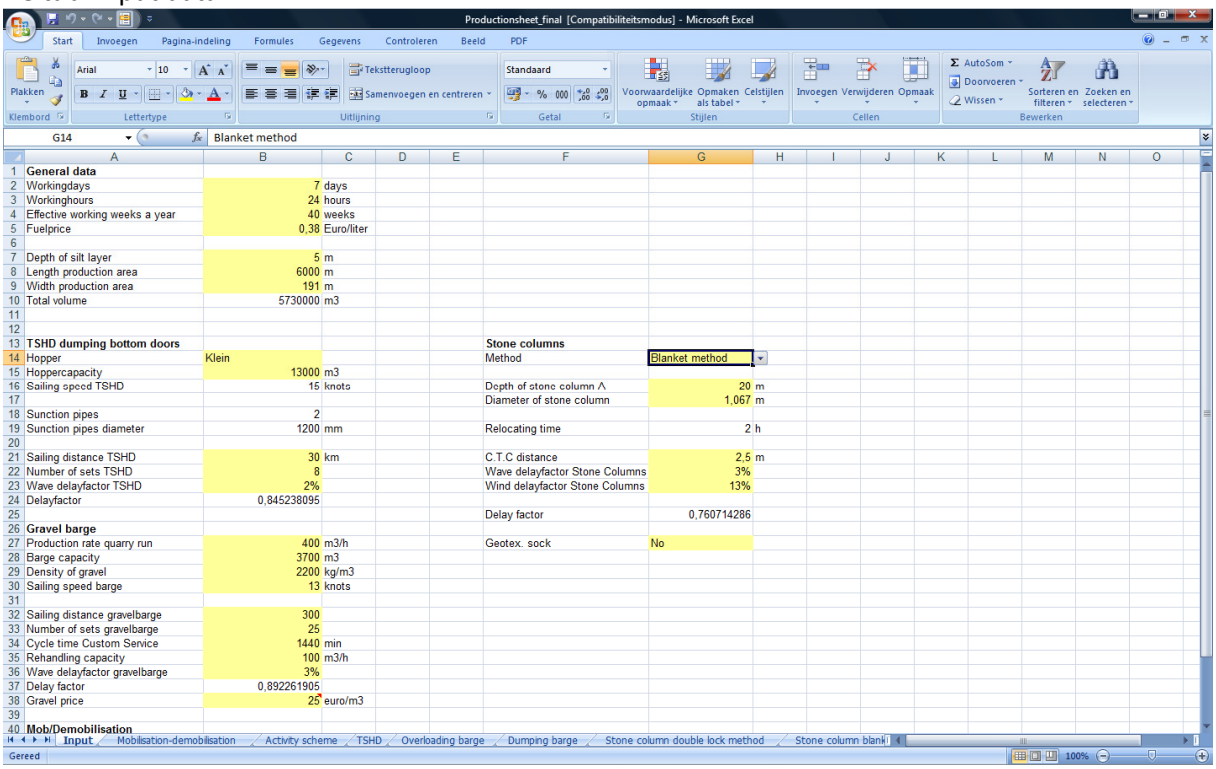
Appendix B: Simplifications and assumptions

In the simulation model, the following simplifications and assumptions are made compared to the actual processes:

- For the model the full length of 6 km Breakwater has to be improved
- Crane on tracks have a rehandling capacity of 100 m3/h
- For the Double Lock Gravel Pump method the capacity of the barge is enough to store the production of the overloaded gravel
- The whole second barge for the production of stone columns with the Double Lock Gravel Pump method can be used for the production
- For the dredging of silt three categories can be used
    - Large: Ships like the Vasco Gamma
    - Medium: Ships like the Nile river
    - Small: Ships like Lange Wapper
- Only small THSD are available, since the large and medium ships are used for the main island
- The stone column efficient factor is 0.85%
- No material fee's are calculated, because no information is available
- The soil layer 1a has to be dredged to create sufficient space for the stone columns
- The dredged silt can be dumped in the Black Sea and not have to be rehandled
- The full opp. of the soil improvement area has to be dredged
- The quarries handed by M-industry are the only one available
- The us dollar rate is at 1.65
- The gallon/liter rate is 0.26
- The delay factors used in the excel model are the same as reference projects in other parts of the world
- The delay factors of barges and stone column barges are the same
- The delay factors are estimated over a whole year, what makes it valuable
- There is no difference in capacity and sailing speed between normal barges and bottom door unloaders
- No time overlap is needed in this phase of the project, because it is only a global planning
- The Olympic effects cannot yet be estimated
- Every time the gravel barge leaves the Russian borders it has to get border clearance
- Quarry further than 40 km of the project site, require the barges to cross the Russian border
- The used equipment only needs reparations and do not have to be replaced and these costs are already in the price of the material
- The gravel price is incl. transport from the quarry to the project site
- Crane on tracks with a width of 12 metres is needed to produce the stone columns from the barges
- The Blanket method has sufficient capacity to make use of a gravel blanket thicker than 3 metres

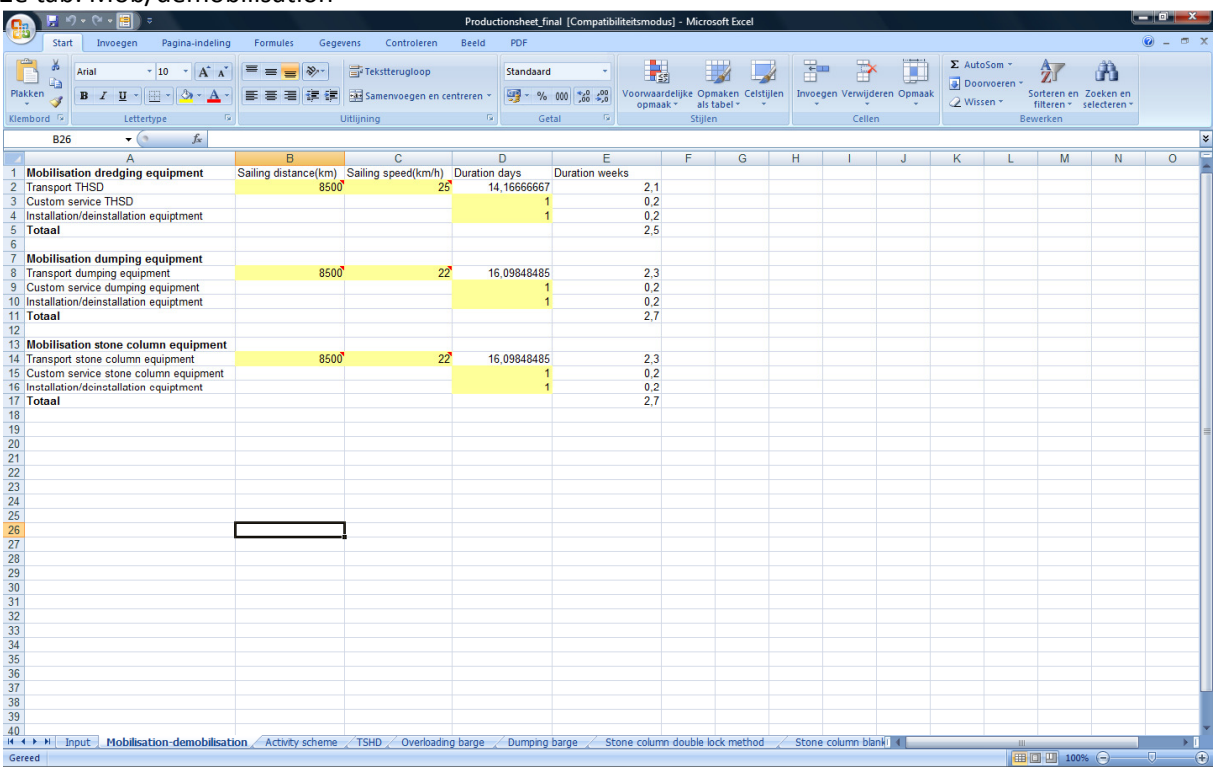
Appendix C Screen shots Excel model

1e tab: Input data



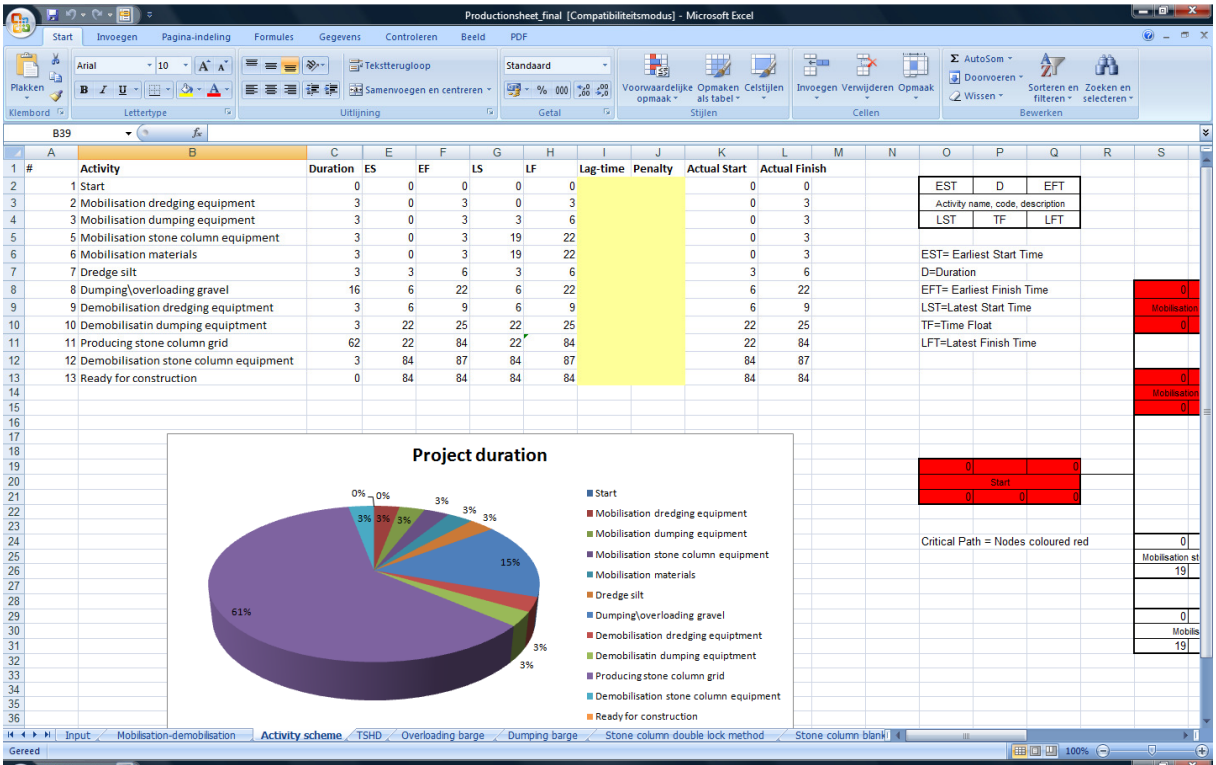
	A	B	C	F	G
1	**General data**				
2	Workingdays	7	days		
3	Workinghours	24	hours		
4	Effective working weeks a year	40	weeks		
5	Fuelprice	0,38	Euro/liter		
6					
7	Depth of silt layer	5	m		
8	Length production area	6000	m		
9	Width production area	191	m		
10	Total volume	5730000	m3		
11					
12					
13	**TSHD dumping bottom doors**			**Stone columns**	
14	Hopper	Klein		Method	Blanket method
15	Hoppercapacity	13000	m3		
16	Sailing speed TSHD	15	knots	Depth of stone column Λ	20 m
17				Diameter of stone column	1,067 m
18	Sunction pipes	2			
19	Sunction pipes diameter	1200	mm	Relocating time	2 h
20					
21	Sailing distance TSHD	30	km	C.T.C distance	2,5 m
22	Number of sets TSHD	8		Wave delayfactor Stone Columns	3%
23	Wave delayfactor TSHD	2%		Wind delayfactor Stone Columns	13%
24	Delayfactor	0,845238095			
25				Delay factor	0,760714286
26	**Gravel barge**				
27	Production rate quarry run	400	m3/h	Geotex. sock	No
28	Barge capacity	3700	m3		
29	Density of gravel	2200	kg/m3		
30	Sailing speed barge	13	knots		
31					
32	Sailing distance gravelbarge	300			
33	Number of sets gravelbarge	25			
34	Cycle time Custom Service	1440	min		
35	Rehandling capacity	100	m3/h		
36	Wave delayfactor gravelbarge	3%			
37	Delay factor	0,892261905			
38	Gravel price	25	euro/m3		
39					
40	**Mob/Demobilisation**				

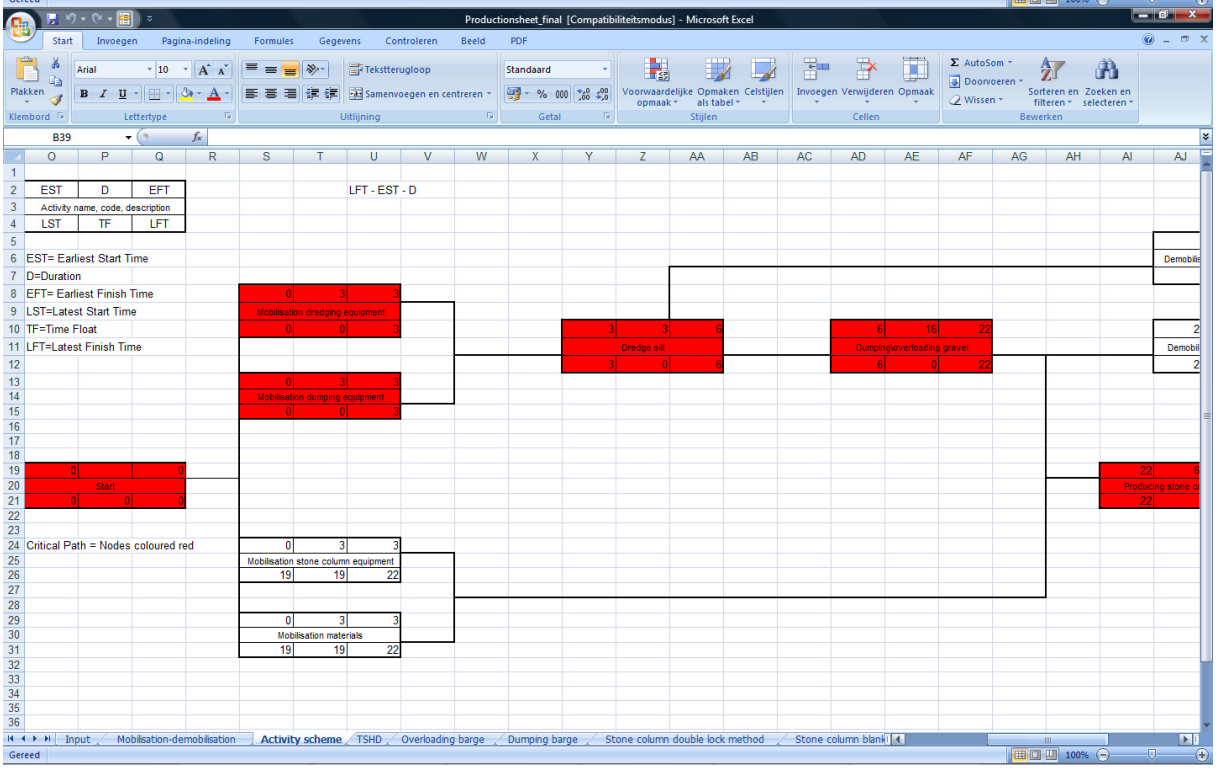
2e tab: Mob/demobilisation



	A	B	C	D	E
1	**Mobilisation dredging equipment**	Sailing distance(km)	Sailing speed(km/h)	Duration days	Duration weeks
2	Transport THSD	8500	25	14,16666667	2,1
3	Custom service THSD			1	0,2
4	Installation/deinstallation equiptment			1	0,2
5	**Totaal**				2,5
6					
7	**Mobilisation dumping equipment**				
8	Transport dumping equipment	8500	22	16,09848485	2,3
9	Custom service dumping equipment			1	0,2
10	Installation/deinstallation equiptment			1	0,2
11	**Totaal**				2,7
12					
13	**Mobilisation stone column equipment**				
14	Transport stone column equipment	8500	22	16,09848485	2,3
15	Custom service stone column equipment			1	0,2
16	Installation/deinstallation equiptment			1	0,2
17	**Totaal**				2,7

3e tab: Activity scheme


Productionsheet_final [Compatibiliteitsmodus] - Microsoft Excel
Project duration
Start
Mobilisation dredging equipment
Mobilisation dumping equipment
Mobilisation stone column equipment
Mobilisation materials
Dredge silt
Dumping\overloading gravel
Demobilisation dredging equiptment
Demobilisatin dumping equiptment
Producing stone column grid
Demobilisation stone column equipment
Ready for construction
61%
15%
3%
0%
Critical Path = Nodes coloured red
EST= Earliest Start Time
D=Duration
EFT= Earliest Finish Time
LST=Latest Start Time
TF=Time Float
LFT=Latest Finish Time
Activity scheme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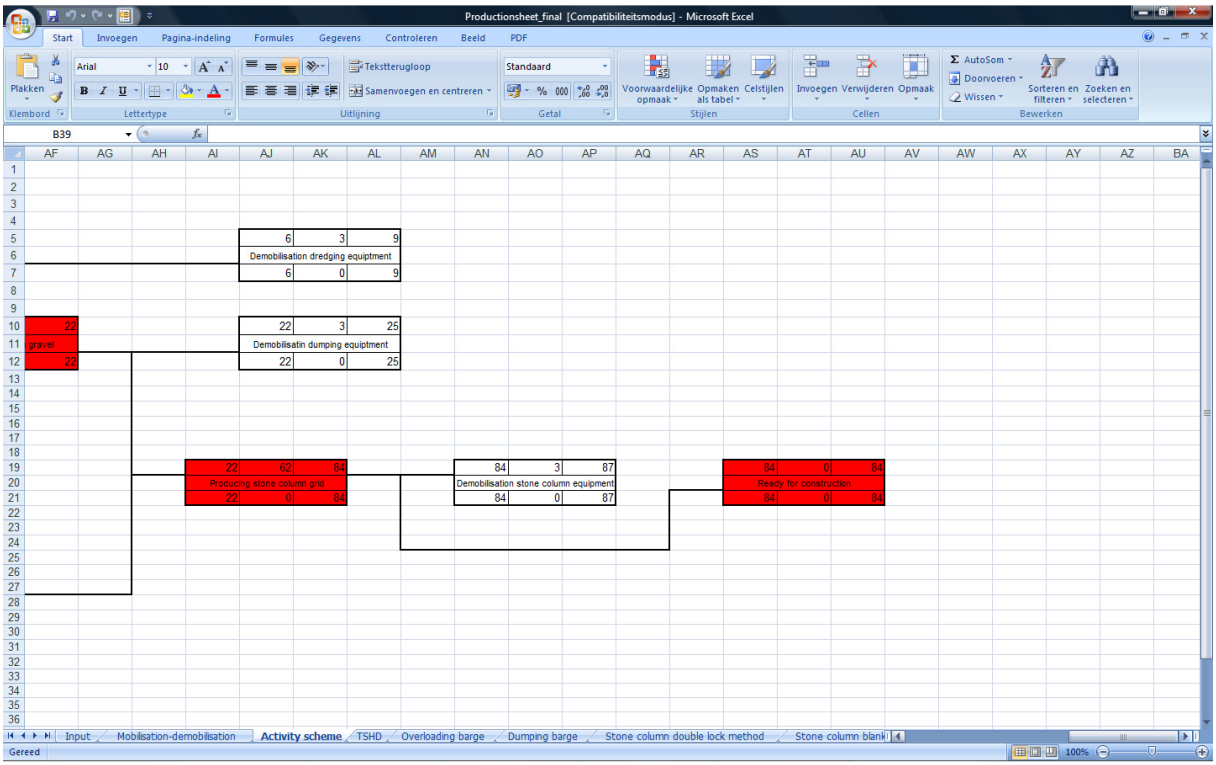
LFT - EST - D
Start
Mobilisation dredging equipment
Mobilisation dumping equipment
Mobilisation stone column equipment
Mobilisation materials
Dredge silt
Dumping\overloading gravel
Critical Path = Nodes coloured red
Activity scheme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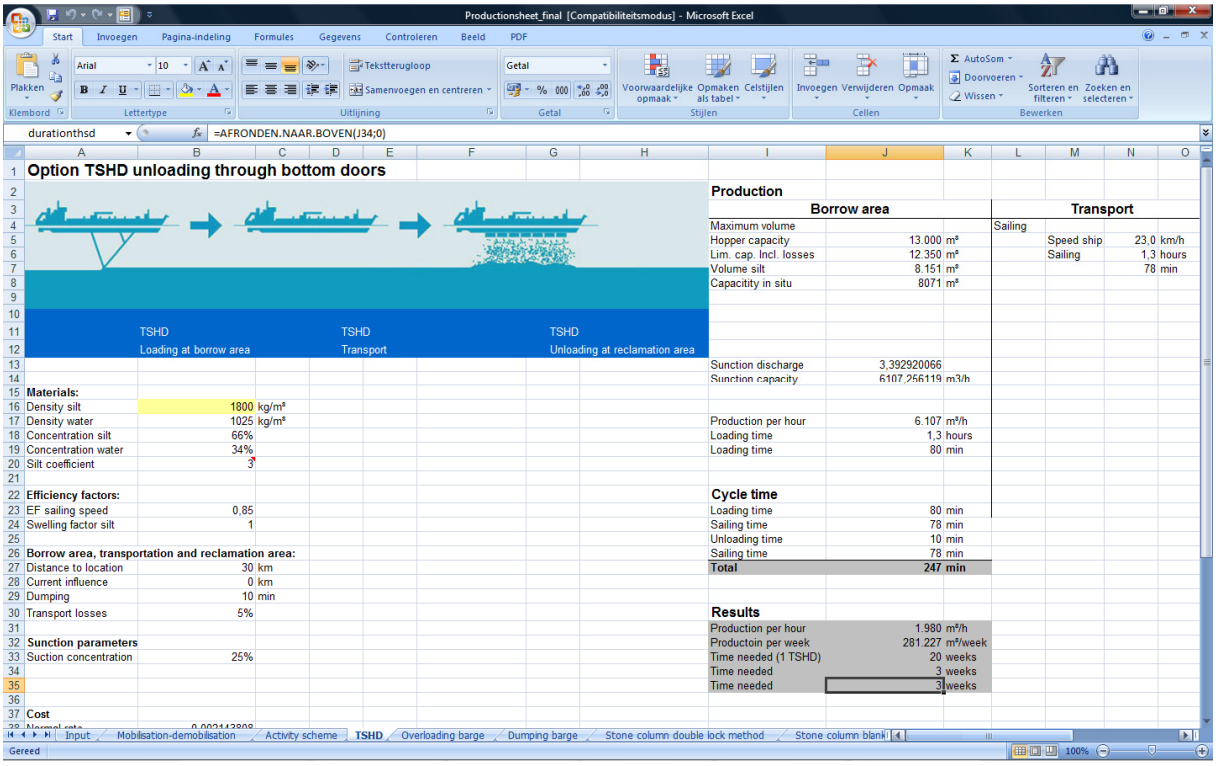
Demobilisation dredging equiptment
Demobilisatin dumping equiptment
gravel
Producing stone column grid
Demobilisation stone column equipment
Ready for construction
Input
Mobilisation-demobilisation
Activity scheme
TSHD
Overloading barge
Dumping barge
Stone column double lock method
Stone column blank

4e tab: THSD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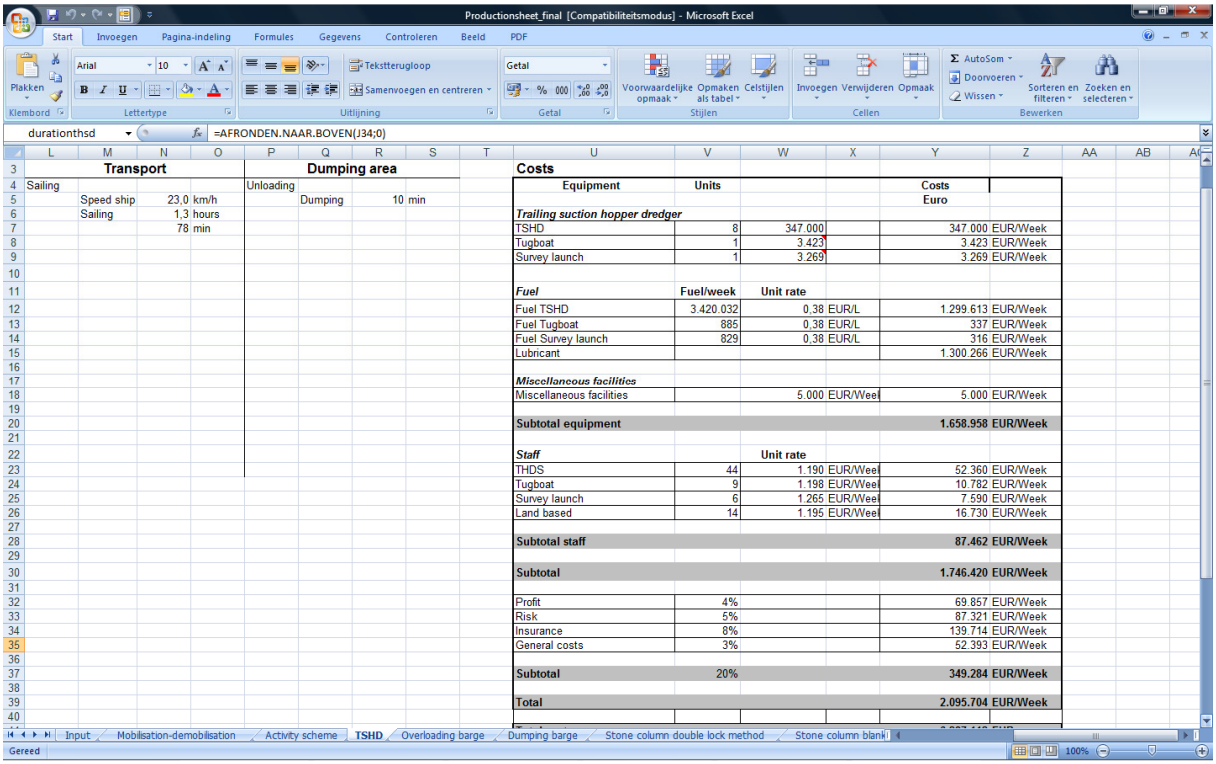
=AFRONDEN.NAAR.BOVEN(J34;0)
Option TSHD unloading through bottom doors
TSHD
Loading at borrow area
TSHD
Transport
TSHD
Unloading at reclamation area
Production
Borrow area
Transport
Maximum volume
Hopper capacity 13.000 m³
Lim. cap. Incl. losses 12.350 m³
Volume silt 8.151 m³
Capacitity in situ 8071 m³
Sailing
Speed ship 23,0 km/h
Sailing 1,3 hours
78 min
Suction discharge 3,392920066
Suction capacity 6107,256119 m3/h
Production per hour 6.107 m³/h
Loading time 1,3 hours
Loading time 80 min
Materials:
Density silt 1800 kg/m³
Density water 1025 kg/m³
Concentration silt 66%
Concentration water 34%
Silt coefficient 3
Efficiency factors:
EF sailing speed 0,85
Swelling factor silt 1
Borrow area, transportation and reclamation area:
Distance to location 30 km
Current influence 0 km
Dumping 10 min
Transport losses 5%
Sunction parameters
Suction concentration 25%
Cost
Cycle time
Loading time 80 min
Sailing time 78 min
Unloading time 10 min
Sailing time 78 min
Total 247 min
Results
Production per hour 1.980 m³/h
Productoin per week 281.227 m³/week
Time needed (1 TSHD) 20 weeks
Time needed 3 weeks
Time needed 3 weeks
Input
Mobilisation-demobilisation
Activity scheme
TSHD
Overloading barge
Dumping barge
Stone column double lock method
Stone column blank



Productionsheet_final [Compatibiliteitsmodus] - Microsoft Excel

durationthsd =AFRONDEN.NAAR.BOVEN(J34;0)

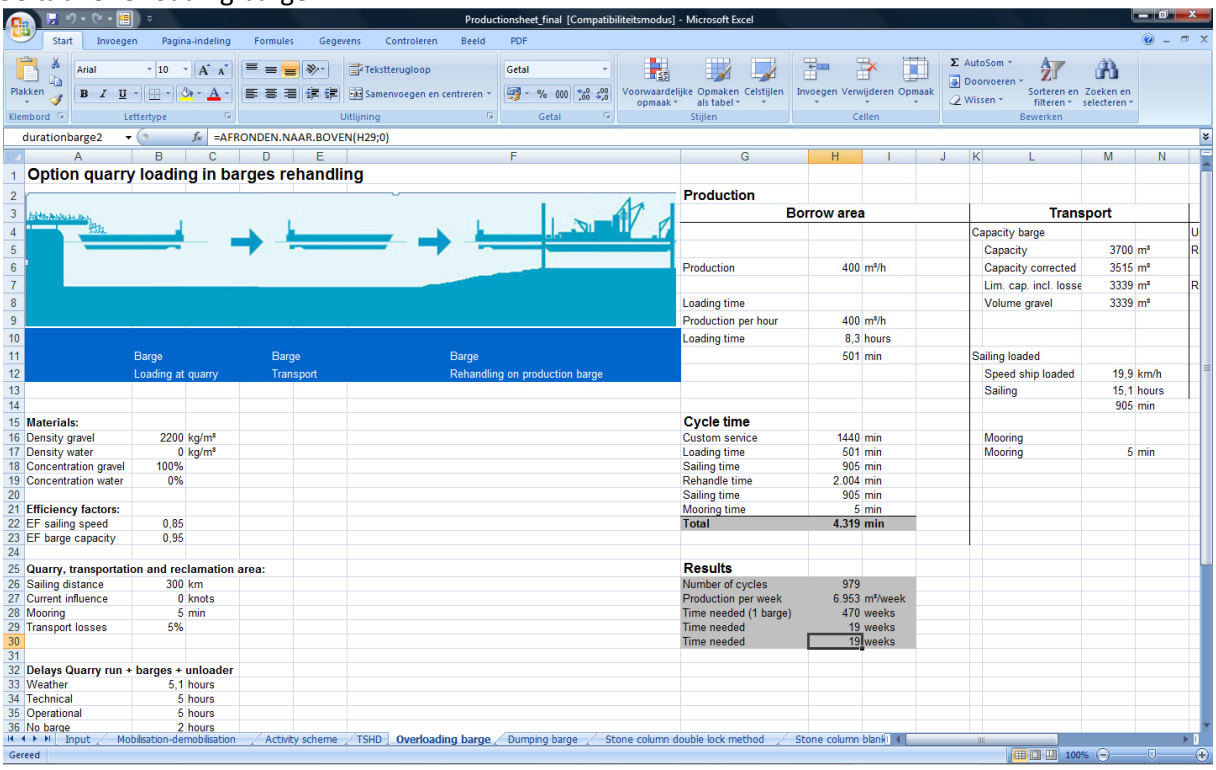
Transport				Dumping area			
Sailing				Unloading			
	Speed ship	23,0	km/h		Dumping	10	min
	Sailing	1,3	hours				
		78	min				

Costs

Equipment	Units		Costs Euro
Trailing suction hopper dredger			
TSHD	8	347.000	347.000 EUR/Week
Tugboat	1	3.423	3.423 EUR/Week
Survey launch	1	3.269	3.269 EUR/Week
Fuel	**Fuel/week**	**Unit rate**	
Fuel TSHD	3.420.032	0,38 EUR/L	1.299.613 EUR/Week
Fuel Tugboat	885	0,38 EUR/L	337 EUR/Week
Fuel Survey launch	829	0,38 EUR/L	316 EUR/Week
Lubricant			1.300.266 EUR/Week
Miscellaneous facilities			
Miscellaneous facilities		5.000 EUR/Week	5.000 EUR/Week
Subtotal equipment			**1.658.958 EUR/Week**
Staff		**Unit rate**	
THDS	44	1.190 EUR/Week	52.360 EUR/Week
Tugboat	9	1.198 EUR/Week	10.782 EUR/Week
Survey launch	6	1.265 EUR/Week	7.590 EUR/Week
Land based	14	1.195 EUR/Week	16.730 EUR/Week
Subtotal staff			**87.462 EUR/Week**
Subtotal			**1.746.420 EUR/Week**
Profit	4%		69.857 EUR/Week
Risk	5%		87.321 EUR/Week
Insurance	8%		139.714 EUR/Week
General costs	3%		52.393 EUR/Week
Subtotal	20%		**349.284 EUR/Week**
Total			**2.095.704 EUR/Week**

Input | Mobilisation-demobilisation | Activity scheme | TSHD | Overloading barge | Dumping barge | Stone column double lock method | Stone column blanket

5e tab: Overloading barge



Productionsheet_final [Compatibiliteitsmodus] - Microsoft Excel

durationbarge2 =AFRONDEN.NAAR.BOVEN(H29;0)

Option quarry loading in barges rehandling

Barge Loading at quarry | Barge Transport | Barge Rehandling on production barge

Materials:		
Density gravel	2200	kg/m³
Density water	0	kg/m³
Concentration gravel	100%	
Concentration water	0%	
Efficiency factors:		
EF sailing speed	0,85	
EF barge capacity	0,95	
Quarry, transportation and reclamation area:		
Sailing distance	300	km
Current influence	0	knots
Mooring	5	min
Transport losses	5%	
Delays Quarry run + barges + unloader		
Weather	5,1	hours
Technical	5	hours
Operational	5	hours
No barge	2	hours

Production

Borrow area			Transport		
			Capacity barge		
			Capacity	3700	m³
Production	400	m³/h	Capacity corrected	3515	m³
			Lim. cap. incl. losse	3339	m³
Loading time			Volume gravel	3339	m³
Production per hour	400	m³/h			
Loading time	8,3	hours			
	501	min	Sailing loaded		
			Speed ship loaded	19,9	km/h
			Sailing	15,1	hours
				905	min

Cycle time

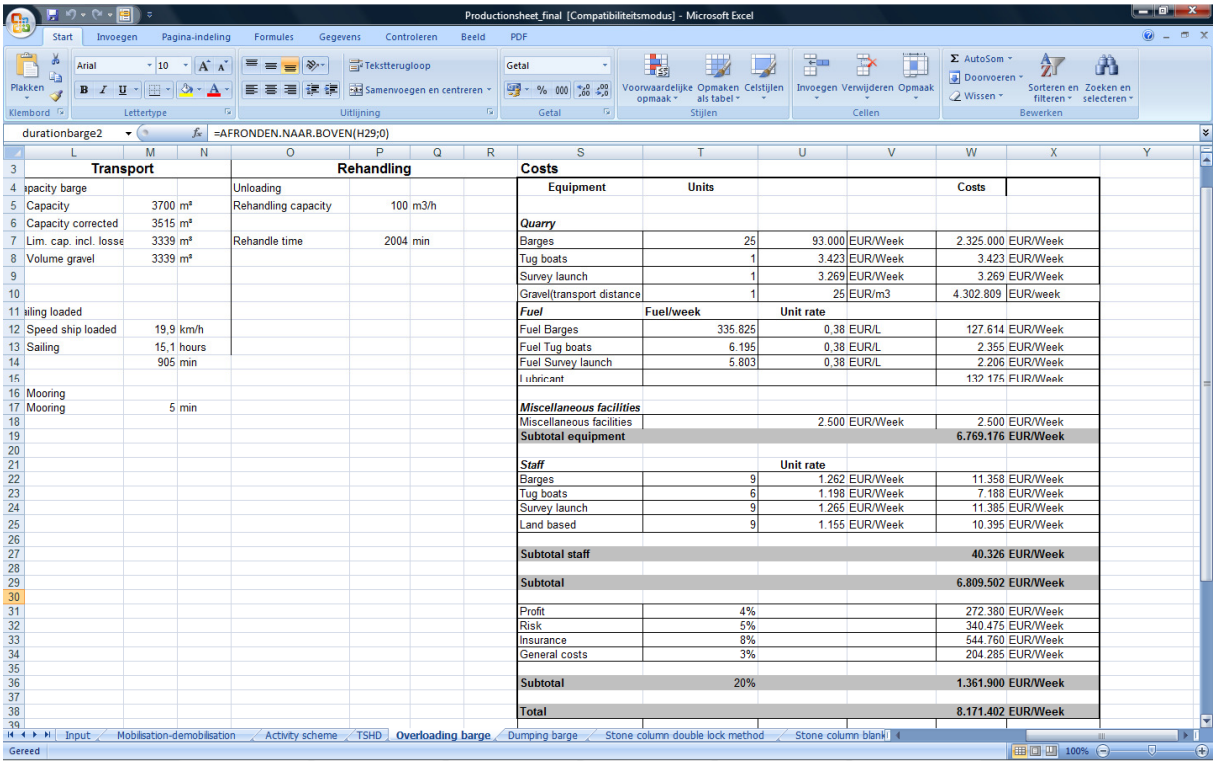
Custom service	1440	min
Loading time	501	min
Sailing time	905	min
Rehandle time	2.004	min
Sailing time	905	min
Mooring time	5	min
Total	**4.319**	**min**

Mooring		
Mooring	5	min

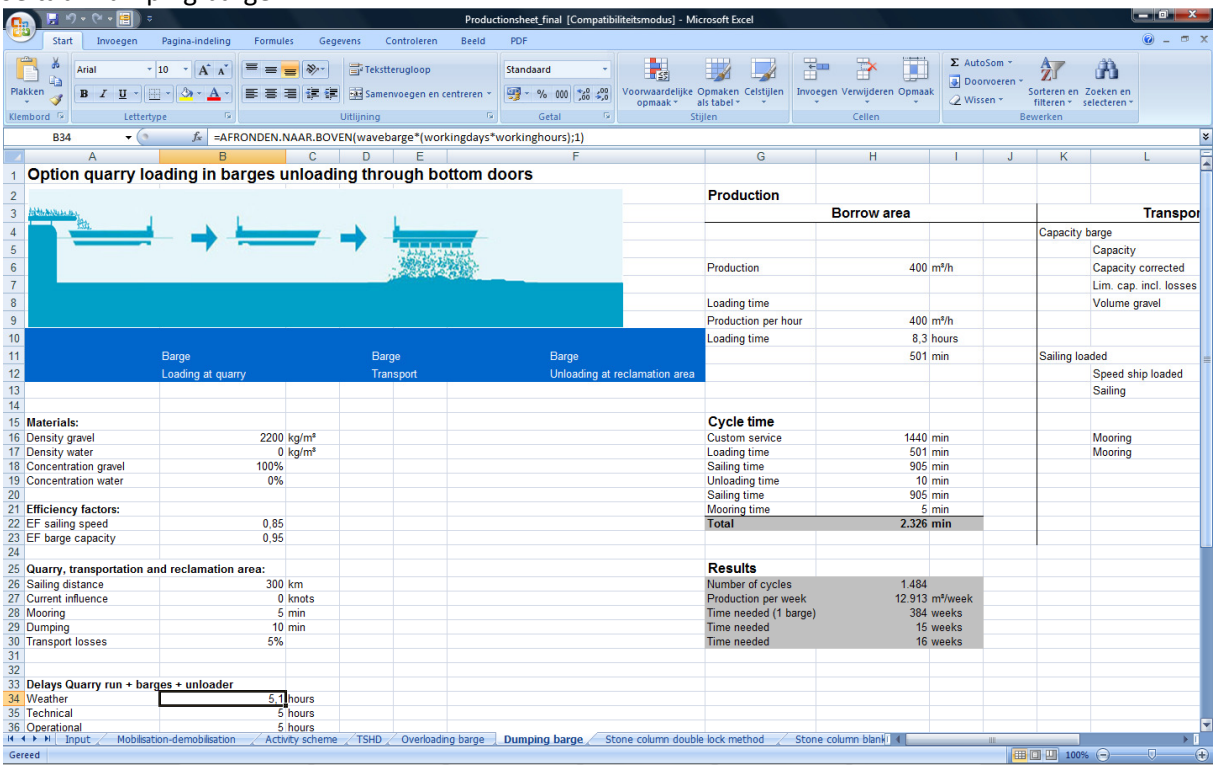
Results

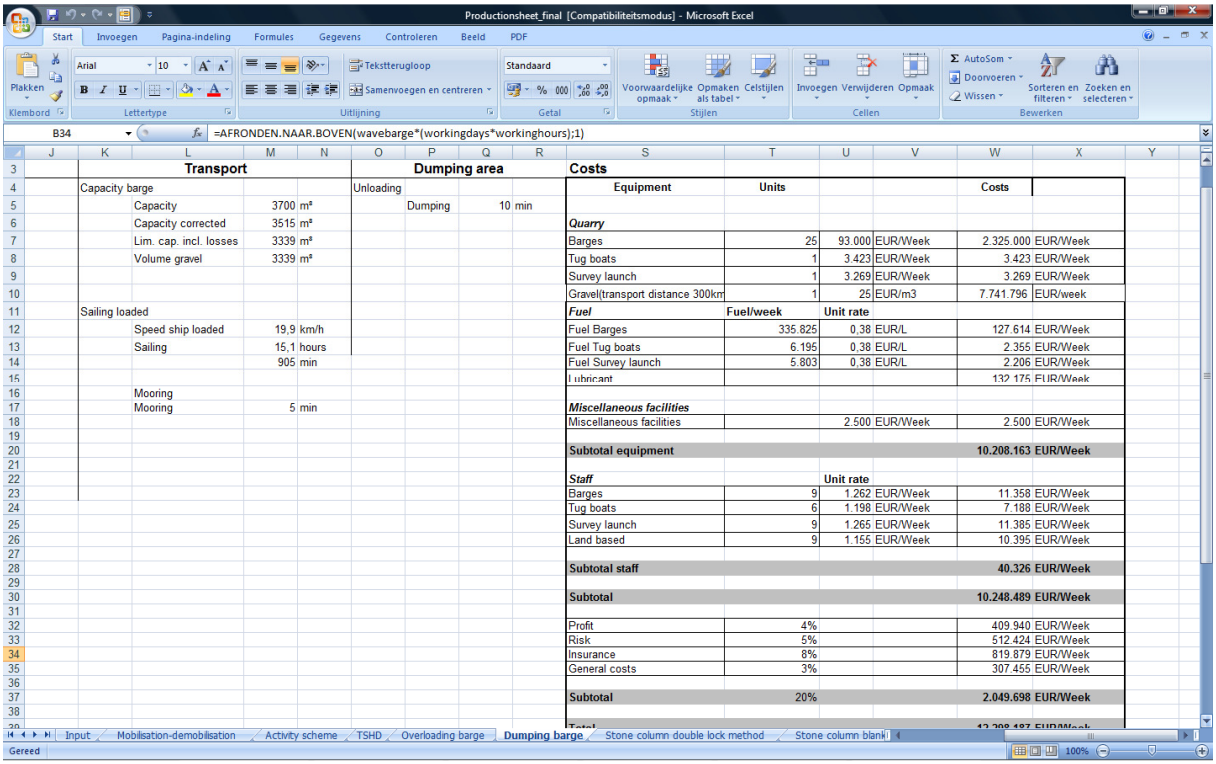
Number of cycles	979	
Production per week	6.953	m³/week
Time needed (1 barge)	470	weeks
Time needed	19	weeks
Time needed	19	weeks

Input | Mobilisation-demobilisation | Activity scheme | TSHD | Overloading barge | Dumping barge | Stone column double lock method | Stone column blanket



6e tab: Dumping barge

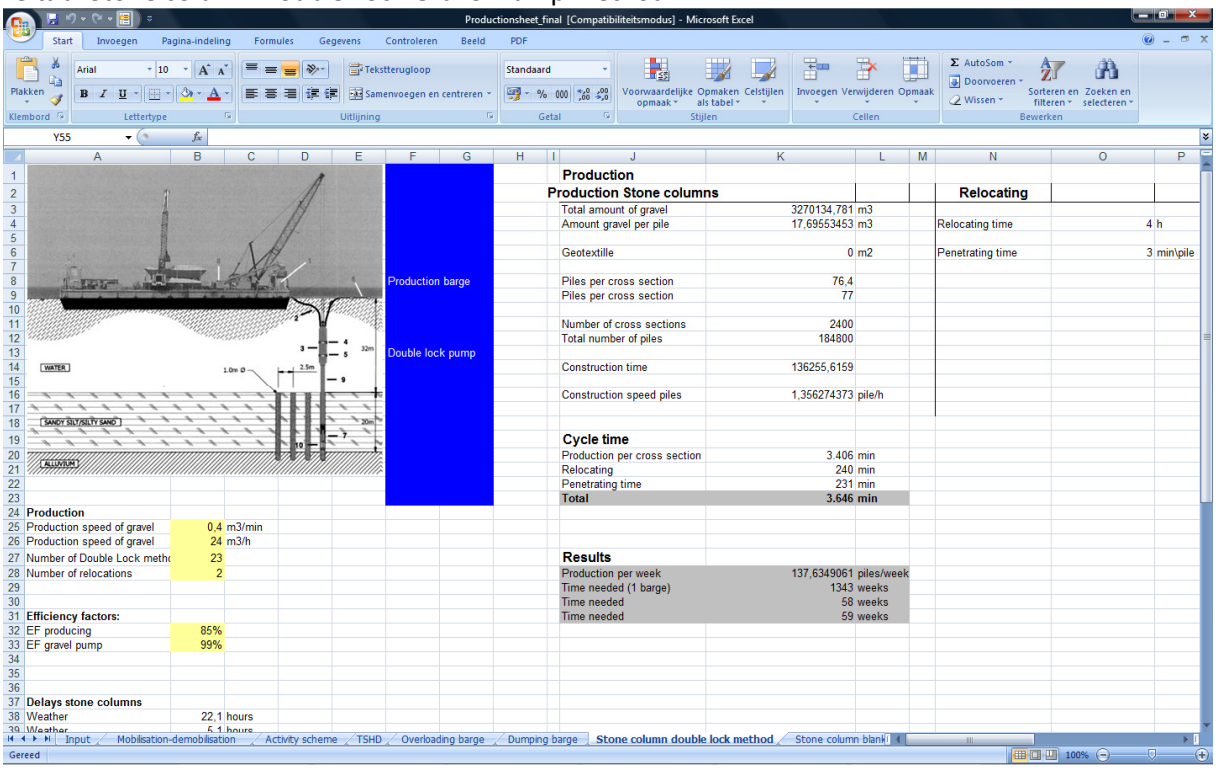




Transport				Dumping area			
Capacity barge				Unloading			
	Capacity	3700	m³		Dumping	10	min
	Capacity corrected	3515	m³				
	Lim. cap. incl. losses	3339	m³				
	Volume gravel	3339	m³				
Sailing loaded							
	Speed ship loaded	19,9	km/h				
	Sailing	15,1	hours				
		905	min				
	Mooring						
	Mooring	5	min				

Costs				
Equipment	Units			Costs
Quarry				
Barges	25	93.000	EUR/Week	2.325.000 EUR/Week
Tug boats	1	3.423	EUR/Week	3.423 EUR/Week
Survey launch	1	3.269	EUR/Week	3.269 EUR/Week
Gravel(transport distance 300km	1	25	EUR/m3	7.741.796 EUR/week
Fuel	Fuel/week	Unit rate		
Fuel Barges	335.825	0,38	EUR/L	127.614 EUR/Week
Fuel Tug boats	6.195	0,38	EUR/L	2.355 EUR/Week
Fuel Survey launch	5.803	0,38	EUR/L	2.206 EUR/Week
Lubricant				132.175 EUR/Week
Miscellaneous facilities				
Miscellaneous facilities		2.500	EUR/Week	2.500 EUR/Week
Subtotal equipment				**10.208.163 EUR/Week**
Staff		Unit rate		
Barges	9	1.262	EUR/Week	11.358 EUR/Week
Tug boats	6	1.198	EUR/Week	7.188 EUR/Week
Survey launch	9	1.265	EUR/Week	11.385 EUR/Week
Land based	9	1.155	EUR/Week	10.395 EUR/Week
Subtotal staff				**40.326 EUR/Week**
Subtotal				**10.248.489 EUR/Week**
Profit	4%			409.940 EUR/Week
Risk	5%			512.424 EUR/Week
Insurance	8%			819.879 EUR/Week
General costs	3%			307.455 EUR/Week
Subtotal	20%			**2.049.698 EUR/Week**

7e tab: Stone column Double Lock Gravel Pump method



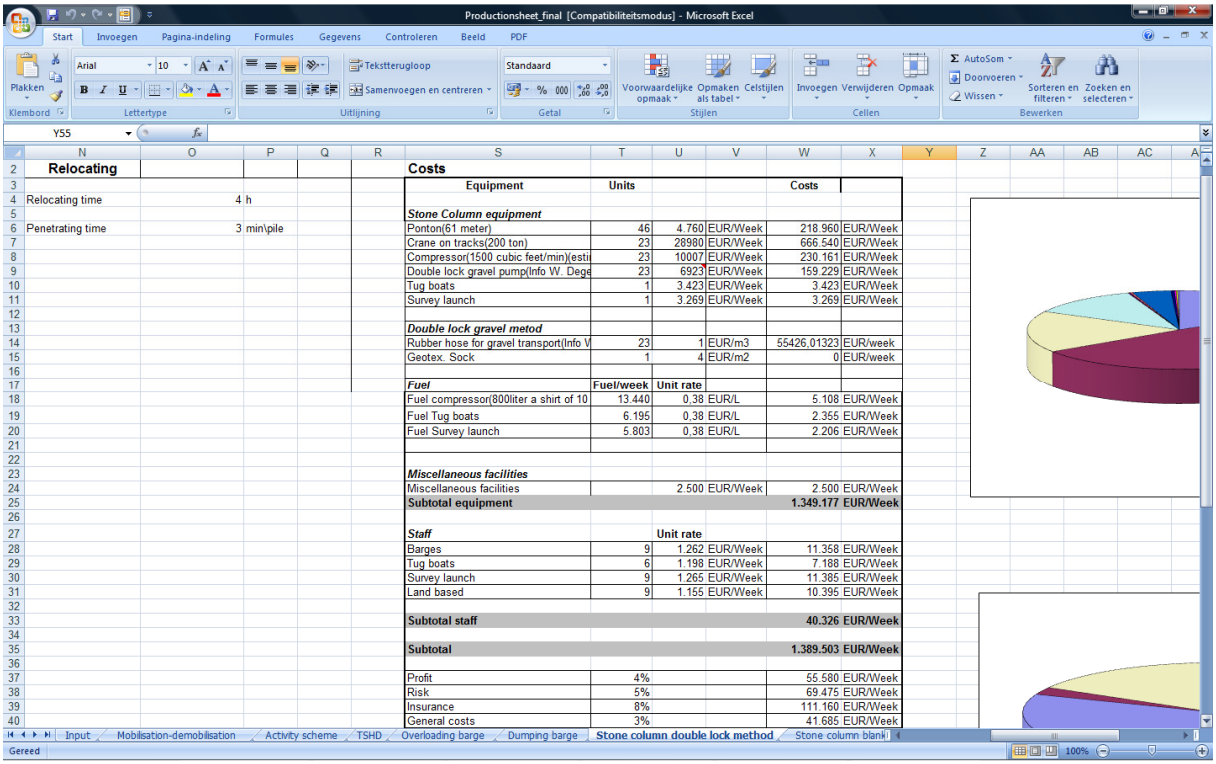
Production		
Production Stone columns		
Total amount of gravel	3270134,781	m3
Amount gravel per pile	17,69553453	m3
Geotextille	0	m2
Piles per cross section	76,4	
Piles per cross section	77	
Number of cross sections	2400	
Total number of piles	184800	
Construction time	136255,6159	
Construction speed piles	1,356274373	pile/h

Relocating		
Relocating time	4	h
Penetrating time	3	min\pile

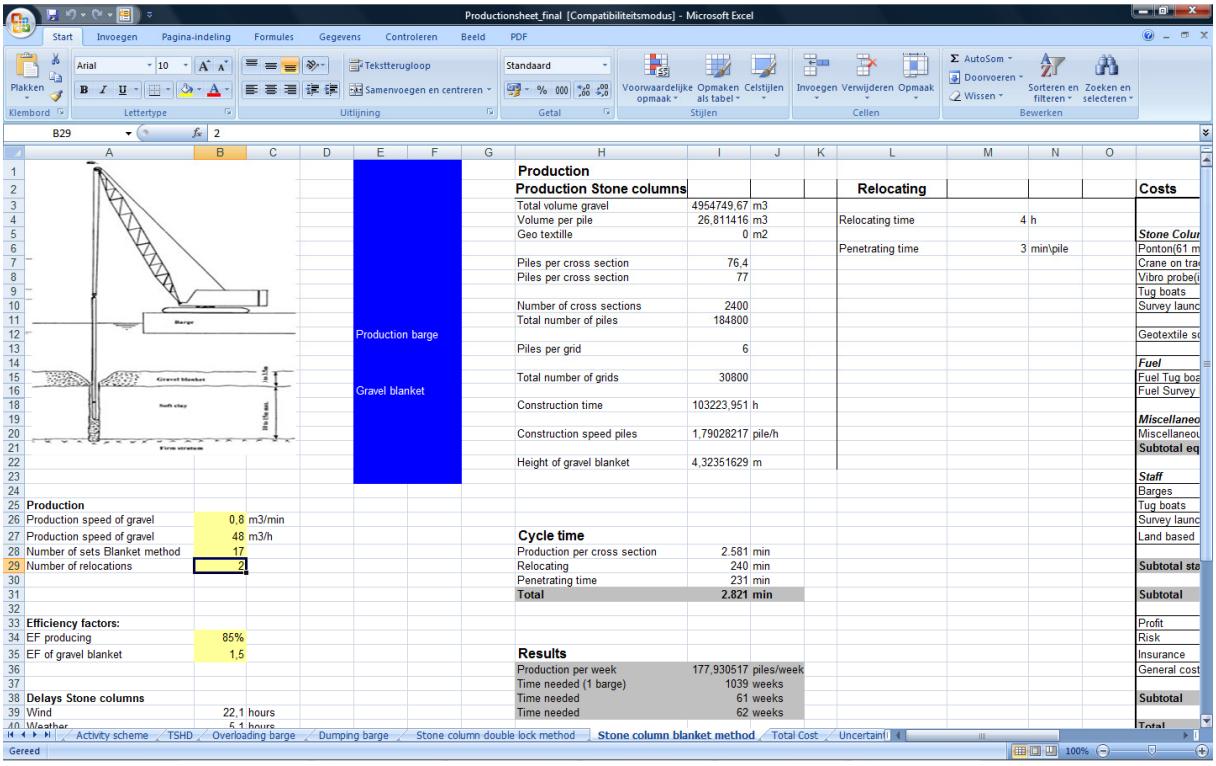
Cycle time		
Production per cross section	3.406	min
Relocating	240	min
Penetrating time	231	min
Total	**3.646**	**min**

Results		
Production per week	137,6349061	piles/week
Time needed (1 barge)	1343	weeks
Time needed	58	weeks
Time needed	59	weeks

Production		
Production speed of gravel	0,4	m3/min
Production speed of gravel	24	m3/h
Number of Double Lock metho	23	
Number of relocations	2	
Efficiency factors:		
EF producing	85%	
EF gravel pump	99%	
Delays stone columns		
Weather	22,1	hours

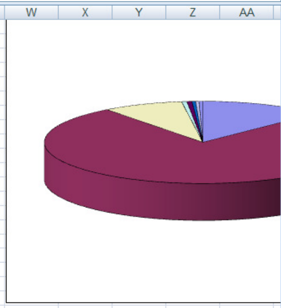


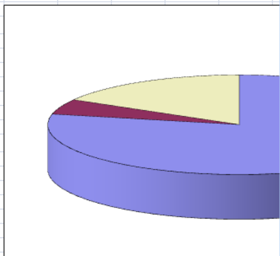
8e tab: Stone column Blanket method



Relocating time	4	h				
Penetrating time	3	min\pile				

Equipment	Units			Costs	
Stone Column equipment					
Ponton(61 meter)	17	4.760	EUR/Week	80.920	EUR/Week
Crane on tracks(200 ton)	17	28980	EUR/Week	492.660	EUR/Week
Vibro probe(information W. Degen)	17	3087	EUR/Week	52.479	EUR/Week
Tug boats	1	3.423	EUR/Week	3.423	EUR/Week
Survey launch	1	3.269	EUR/Week	3.269	EUR/Week
Geotextile sock	1	4	EUR/m2	0	EUR/Week
Fuel	**Fuel/week**	**Unit rate**			
Fuel Tug boats	6.195	0,38	EUR/L	2.355	EUR/Week
Fuel Survey launch	5.803	0,38	EUR/L	2.206	EUR/Week
Miscellaneous facilities					
Miscellaneous facilities		2.500	EUR/Week	2.500	EUR/Week
Subtotal equipment				**639.812**	**EUR/Week**
Staff		**Unit rate**			
Barges	9	1.262	EUR/Week	11.358	EUR/Week
Tug boats	6	1.198	EUR/Week	7.188	EUR/Week
Survey launch	9	1.265	EUR/Week	11.385	EUR/Week
Land based	9	1.155	EUR/Week	10.395	EUR/Week
Subtotal staff				**40.326**	**EUR/Week**
Subtotal				**680.138**	**EUR/Week**
Profit	4%			27.206	EUR/Week
Risk	5%			34.007	EUR/Week
Insurance	8%			54.411	EUR/Week
General costs	3%			20.404	EUR/Week
Subtotal	**20%**			**136.028**	**EUR/Week**
Total				**816.166**	**EUR/Week**
Total cost				**50.602.267**	**EUR**





9e tab: Total costs

#	Activity	Cost/week	
1	Start	0	EUR/week
2	Mob/demob dredging equipment	2.095.704	EUR/week
3	Mob/demob dumping equipment	3008032	EUR/week
5	Mob/demob stone column equipment	816166	EUR/week
7	Dredge silt	2.095.704	EUR/week
8	Dumping/overloading gravel	12298187	EUR/week
9	Producing stone column grid	816166	EUR/week
10	Ready for construction	0	EUR/week

m3	4954749,668
m2	1146000
m	6000

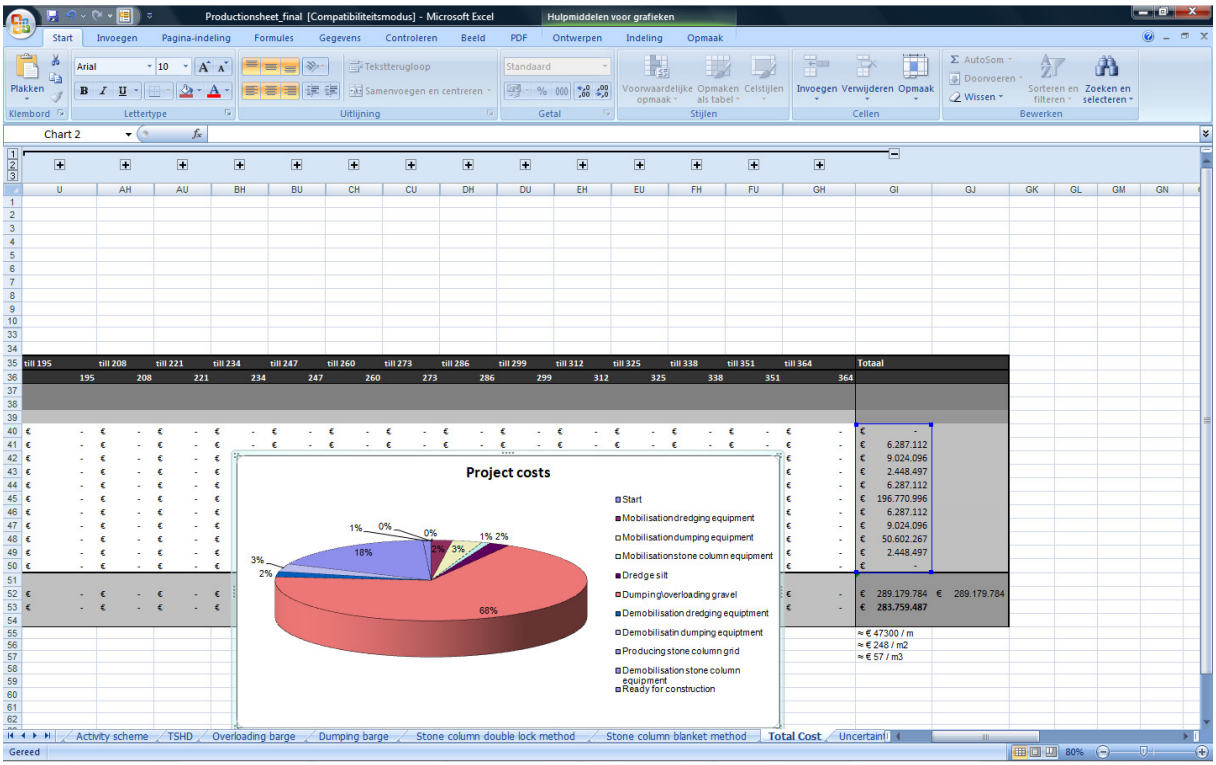
Determing NPV

Uitgaven

Arbeidskosten	Start	Finish	Duration	Totaal Price/week	till 195	till 208	till 221	till 234	till 247	till 260	till 273	till 286	till 299
Weeks					195	208	221	234	247	260	273	286	
Start	0	0	0	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Mobilisation dredging equipment	0	3	3	€ 2.095.704	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Mobilisation dumping equipment	0	3	3	€ 3.008.032	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Mobilisation stone column equipment	0	3	3	€ 816.166	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Dredge silt	3	6	3	€ 2.095.704	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Dumping\overloading gravel	6	22	16	€ 12.298.187	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Demobilisation dredging equiptment	6	9	3	€ 2.095.704	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Demobilisatin dumping equiptment	22	25	3	€ 3.008.032	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Producing stone column grid	22	84	62	€ 816.166	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Demobilisation stone column equipment	84	87	3	€ 816.166	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Ready for construction	84	84	0	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Total kosten					€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Total Netto Costs					€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -

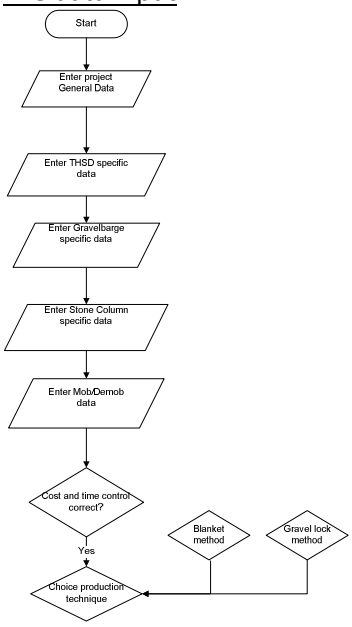
Economic factors

Interest Rate (jaar)	1,09	1,001658637	Totaal R (jaar)	0,9541
Inflation Rate (jaar)	1,04	1,000754529	Totaal R (week)	0,9991

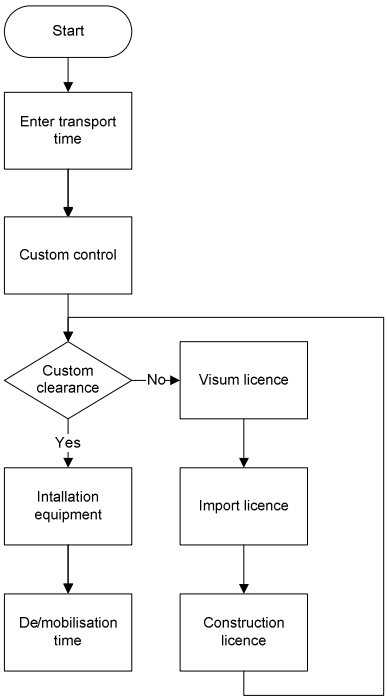

Productionsheet_final [Compatibiliteitsmodus] - Microsoft Excel
Hulpmiddelen voor grafieken
Project costs
Start
Mobilisationdredging equipment
Mobilisationdumping equipment
Mobilisationstone column equipment
Dredge silt
Dumpingloverloading gravel
Demobilisation dredging equiptment
Demobilisatin dumping equiptment
Producing stone column grid
Demobilisation stone column equipment
Ready for construction
1%
0%
0%
1%
2%
3%
18%
3%
2%
68%
Totaal
€ 6.287.112
€ 9.024.096
€ 2.448.497
€ 6.287.112
€ 196.770.996
€ 6.287.112
€ 9.024.096
€ 50.602.267
€ 2.448.497
€ 289.179.784
€ 283.759.487
≈ € 47300 / m
≈ € 248 / m2
≈ € 57 / m3
Activity scheme
TSHD
Overloading barge
Dumping barge
Stone column double lock method
Stone column blanket method
Total Cost
Gereed

Appendix D Flowcharts of construction model

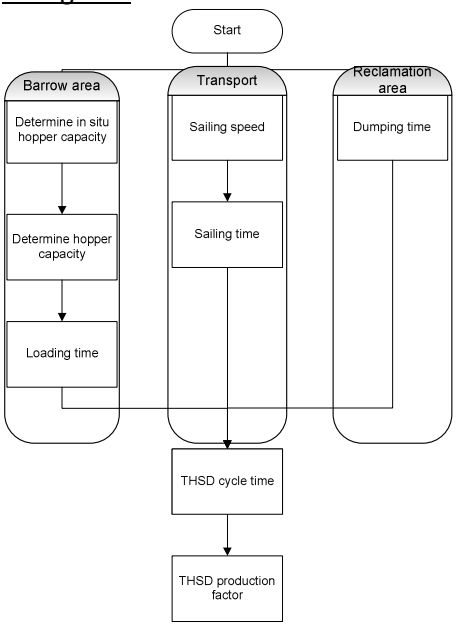
The data input



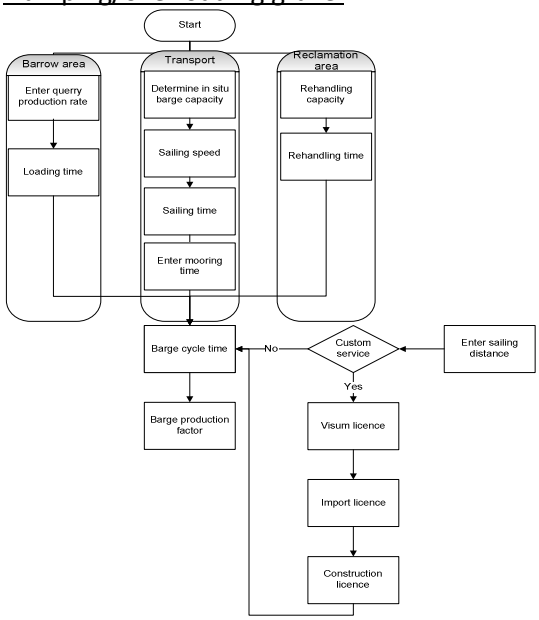
Mob/demobilisation



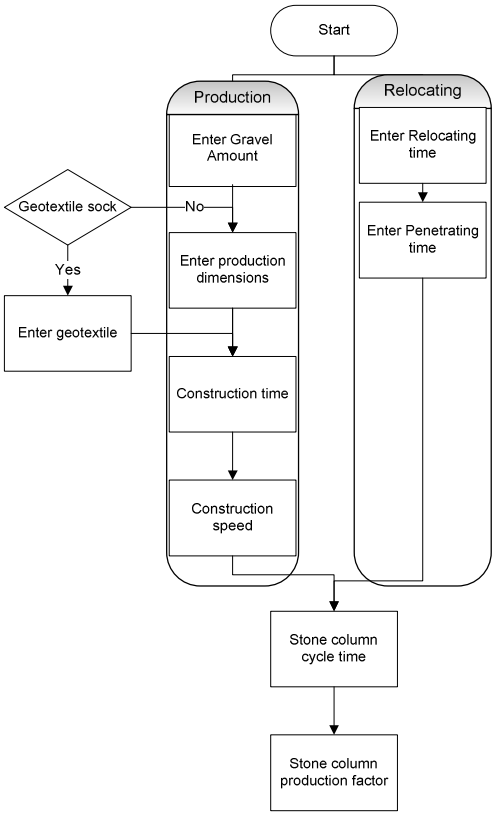
Dredge silt



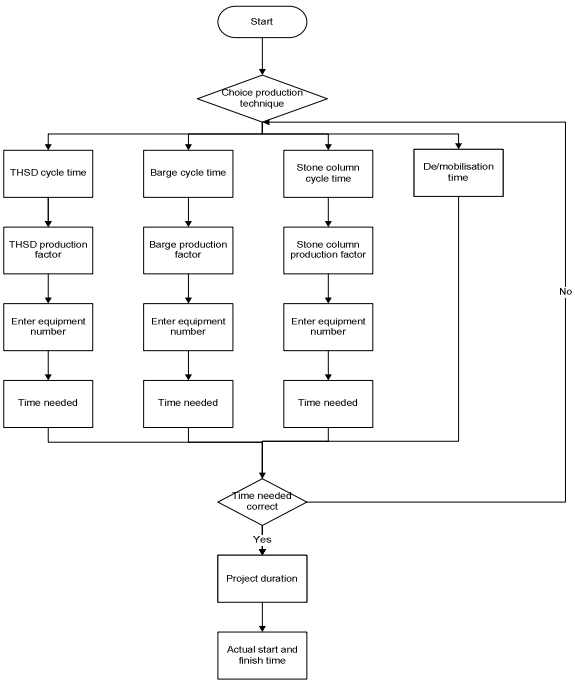
Dumping/overloading gravel



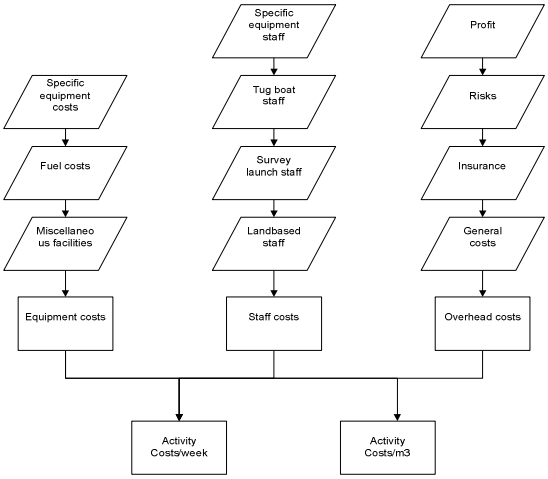
Producing Stone columns



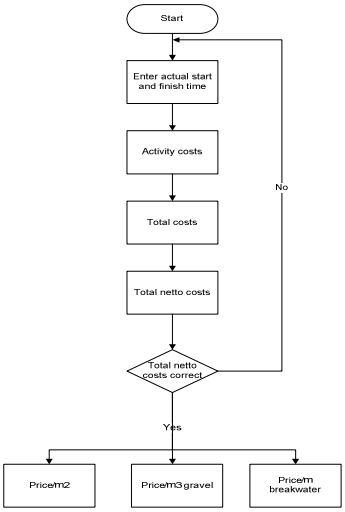
Project time



Activity costs



Project costs



Appendix E Verification of the Excel model

The verification process was done for the activities; Dredge silt, Dumping gravel and overloading gravel. The Excell model was compared with a model made by a Witteveen+Bos expert. The model of the expert is also used in other project to predict outcomes of these kind of activities. This makes the model reliable enough to use it for this verification.

Verification dredge silt

Input data			
Density silt	1800	kg/m³	
Density water	1025	kg/m³	
Concentration silt	66%		
Concentration water	34%		
Silt coefficient	3		
Hopper capacity	13000	m³	
Lim. cap. Incl. losses	12350	m³	
Volume silt	8151	m³	
Capacitity in situ	8071	m³	
Verification output	**Excel model**	**Validation model**	**Validation factor**
Cycle time	247	237	-4%
Production/hour	1980	2062	4%
Production/week	281227	292825	4%
Costs/m3	3,85	3,97	3%

Verification dumping gravel

Input data			
Materials:			
Density gravel	2200	kg/m³	
Density water	0	kg/m³	
Concentration gravel	100%		
Concentration water	0%		
Quarry, transportation and reclamation area:			
Sailing distance	300	km	
Current influence	0	knots	
Mooring	5	min	
Transport losses	5%		
Production quarry	400	m3/h	
Verification output	**Excel model**	**Validation model**	**Validation factor**
Cycle time	2326	2303	-1%
Production/week	12913	13041	1%
Costs/m3	40,16	39,31	-2%

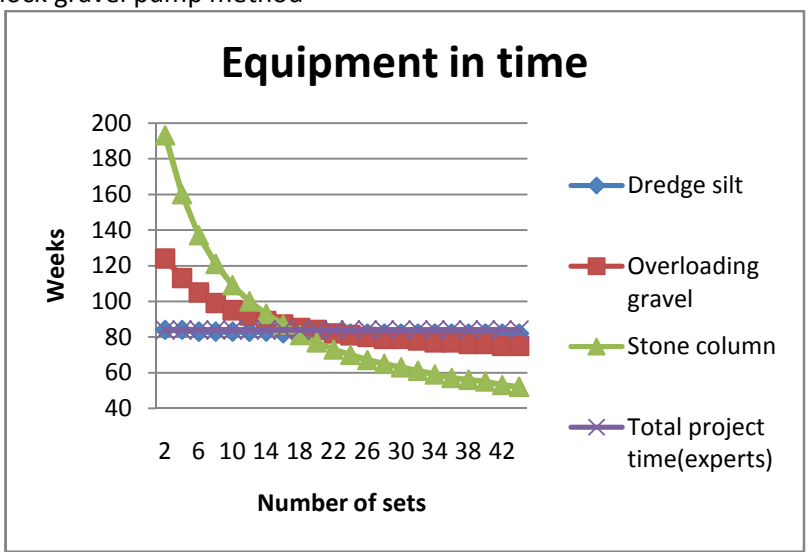
Verification overloading gravel

Input data			
Materials:			
Density gravel	2200	kg/m³	
Density water	0	kg/m³	
Concentration gravel	100%		
Concentration water	0%		
Quarry, transportation and reclamation area:			
Sailing distance	300	km	
Current influence	0	knots	
Mooring	5	min	
Transport losses	5%		
Production quarry	400	m3/h	
Verification output	**Excel model**	**Validation model**	**Validation factor**
Cycle time	4319	4302	-0,395%
Production/week	6953	6981	0,401%
Costs/m3	47,48	47,37	-0,232%

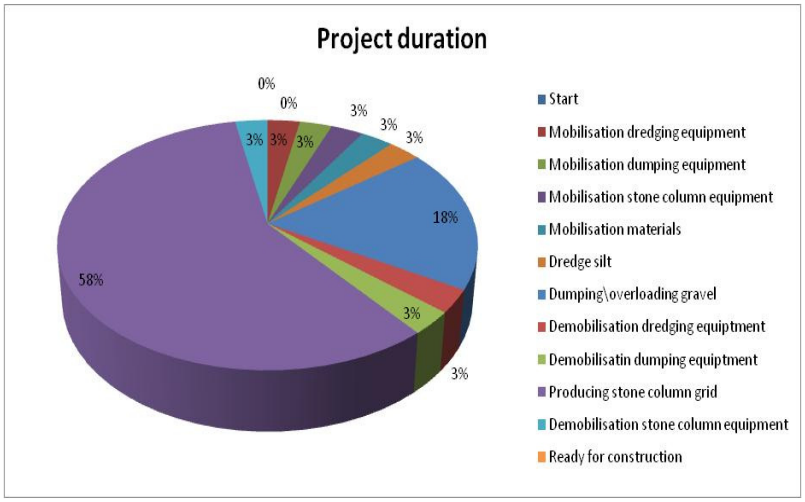
Appendix F Graphical results of test simulation

In this appendix the graphical results of the test simulation are displaced. They are categorised by soil improvement techniques. For both techniques first the results in time are given and they are followed by the results in costs.

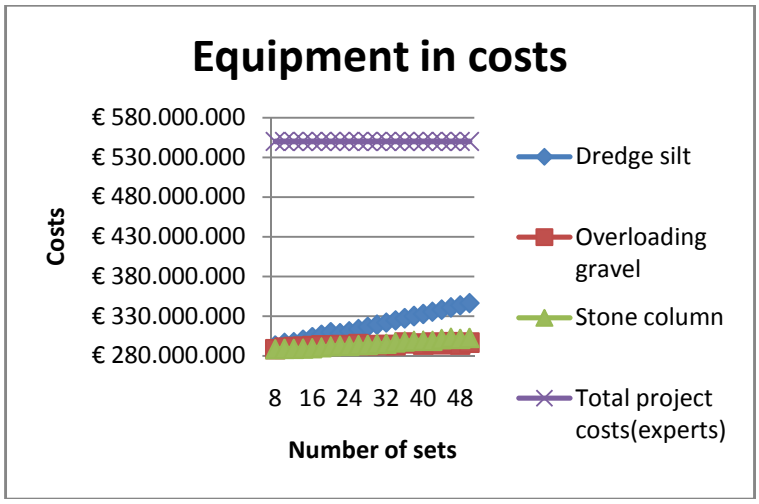
Double lock gravel pump method



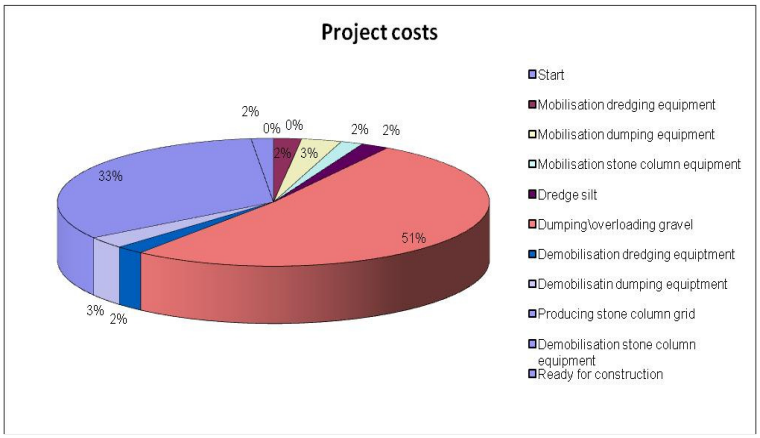
The relation between total project time and the number of equipment with Double lock gravel pump method



Circle diagram of total project duration, divided by the activities

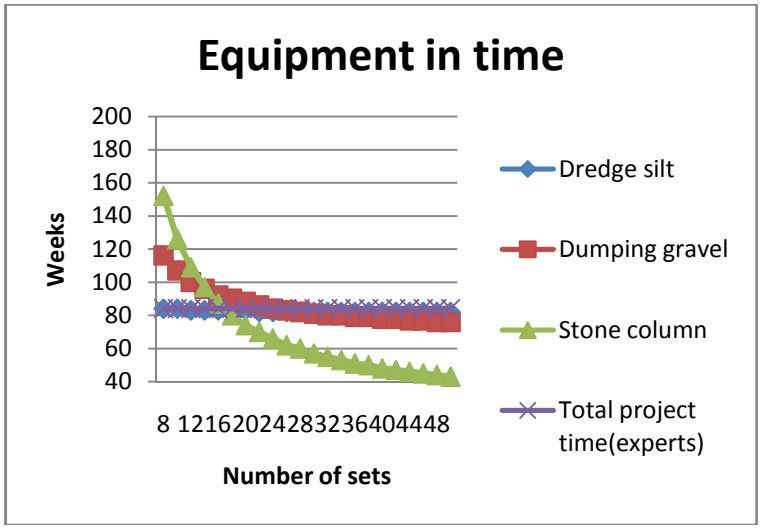


The relation between total project costs and the number of equipment with Double lock gravel pump method

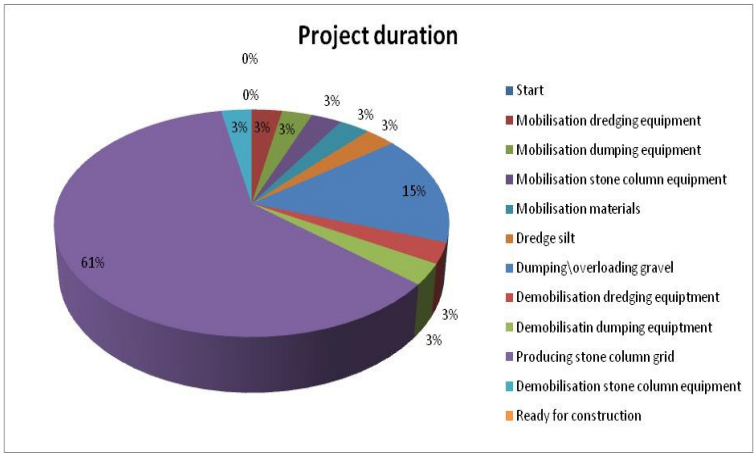


Circle diagram of total project cost, divided by the activities

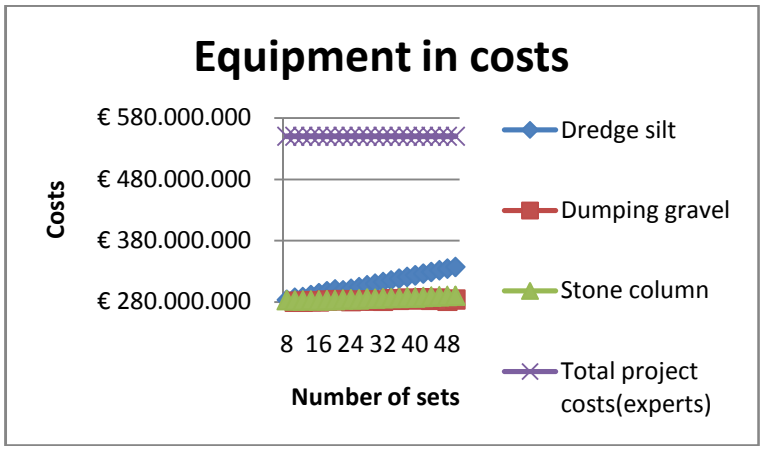
Blanket method



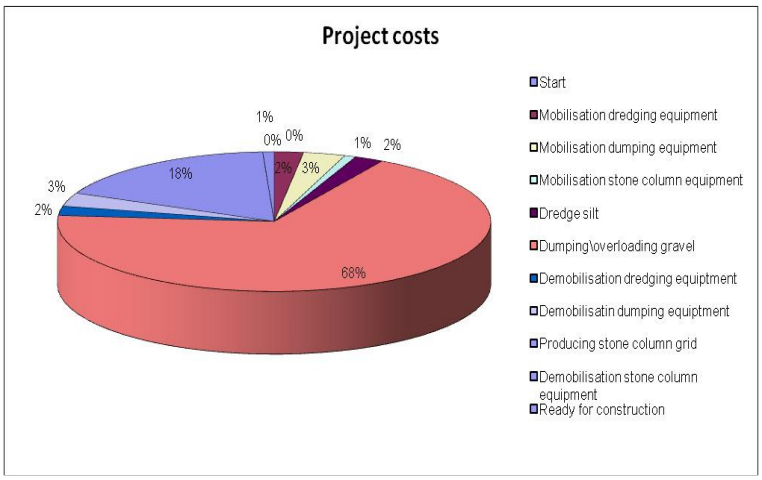
The relation between total project time and the number of equipment with Blanket method



Circle diagram of total project duration, divided by the activities



The relation between total project costs and the number of equipment with Blanket method



Circle diagram of total project cost, divided by the activities

Appendix G Input data and uncertainties

The input data used for the Excel model is indicated in yellow. For all input data uncertainties were determined, which also is in this table.

		Minimal	Most Likely	Maximal	Unit
Risk identificatie per activiteit					
Start					
The working hours are not that high as expected		120	168	168	Hours/week
The effective working weeks in a year are uncertain in Russia.		35	40	45	Weeks
Contractor 1					
	Mobilisation dredging equipment				
	-Only small hoppers are available for the dredging of silt.	3	6	44	Weeks
	-Not enough small equipment is available, which can badly influence the time table.	1	8	15	Sets
	-Uncertaintity in mob/demob	1	4	14	Weeks
	-Sailing distance further	7600	8500	16300	
	Dredge silt				
	-More or less of layer 1a has to be dredged	4,5	5	6,5	Meter
	-The density of to dredge material	1400	1800	1900	kg/m3
	The sailing distance is higher as expected.	20	30	40	km
	-Exeptional weather conditions	1%	2%	6%	factor
	-Price hikes/inflations in fuel	0,215172414	0,340689655	0,627586207	Euro/liter
	Mobilisation dumping equipment				
	-Availability of dumping equipment.	1	25	50	Sets
	-Uncertaintity in mob/demob	1	4	14	Weeks
	-Sailing distance further	7600	8500	16300	
	Mobilisation gravel				
	-The availability of gravel, it is poor in the black sea, which can lead to higher sailing distances.	40	300	350	km
	-The production rate of the quarry.	200	400	800	m3/h
	-Exeptional weather conditions	1%	3%	10%	factor
	-Price hikes/inflations in fuel	0,215172414	0,340689655	0,627586207	Euro/liter
	-Price hikes/inflations in materials	29,43650126	35	41,615	Euro/m3
	-Temporary import/export of equipment	120	1440	120960	min
	Dumping/overloading gravel				
	-The given length of the breakwater is not accurate	3500	6000	6500	Meter
	-Capacity of overloading crane is not sufficient	60	100	120	m3/h
Contractor 2					
	Mobilization stone column equipment				
	-Not enough equipment is available	1	5	25	Sets
	-Uncertaintity in mob/demob	1	4	14	Weeks
	-Sailing distance further	7600	8500	16300	
	Producing stone column				
	-The depth of the stone column is not accurate	15	20	25	Meter
	The length of The breakwater to be funded on stone columns is not accurate	3500	6000	6100	Meter
	-The given column diameter is not accurate.	0,7	1	1,1	Meter
	-The production rate is not accurate.	0,35 of 0,7	0,4 of 0,8	0,5 of 1	m3/h
	-The effiency of gravel production of blanket method is an uncertainty	1,2	1,5	2	factor
	The c.t.c. distance is an uncertainty	1,5	2,5	2,5	meter
	-Geo textile socks have to be used	no	no	yes	
	-The price of The Geo textile sock are uncertain	3	4	6	m2
	-Exeptional weather conditions	1%	3%	10%	Sets
	Exceptional wind conditions	5%	13%	26%	
	-Price hikes/inflations in fuel	0,215172414	0,340689655	0,627586207	Euro/liter
Relocating barges					
-The relocation of the barge is more time consuming as expected.		1,538461538	2	2,6	Hours

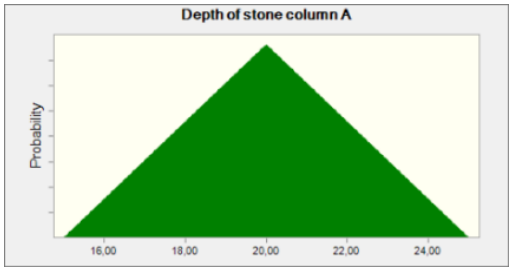
Appendix H Risk distributions

In this appendix the distributions of the different uncertainties.

Distribution stone column length

Triangular distribution with parameters(m):

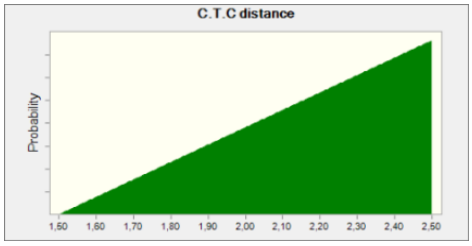
Minimum	15,00
Likeliest	20,00
Maximum	25,00



Distribution of C.T.C distance

Triangular distribution with parameters(m):

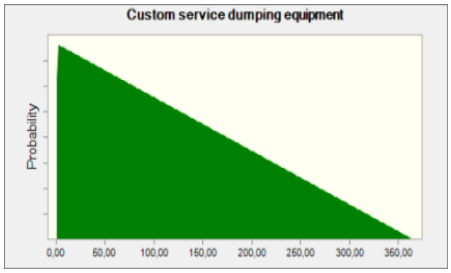
Minimum	1,50
Likeliest	2,50
Maximum	2,50



Distribution Custom service

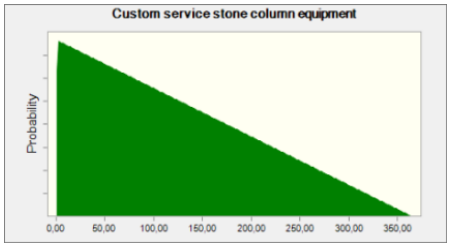
Triangular distribution with parameters(weeks):

Minimum	0,50
Likeliest	1,00
Maximum	364,00



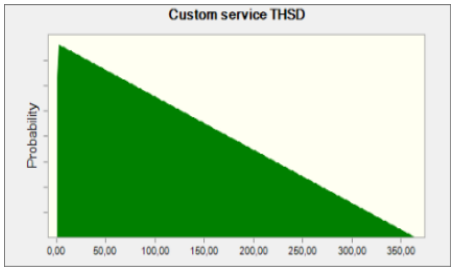
Triangular distribution with parameters(weeks):

Minimum	0,50
Likeliest	1,00
Maximum	364,00



Triangular distribution with parameters(weeks):

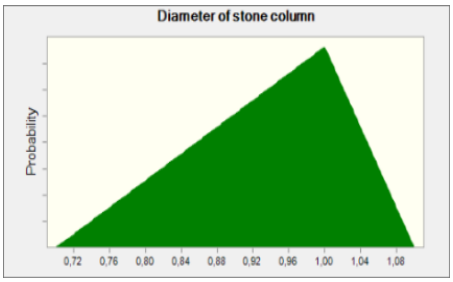
Minimum	0,50
Likeliest	1,00
Maximum	364,00



Distribution of stone columns diameter

Triangular distribution with parameters(m):

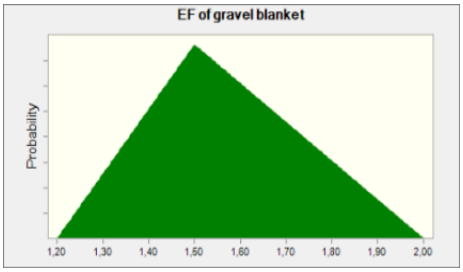
Minimum	0,70
Likeliest	1,00
Maximum	1,10



Distribution of Effective Factor gravel production

Triangular distribution with parameters:

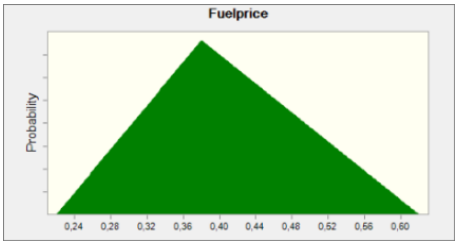
Minimum	1,20
Likeliest	1,50
Maximum	2,00



Distribution of gravel and fuel price

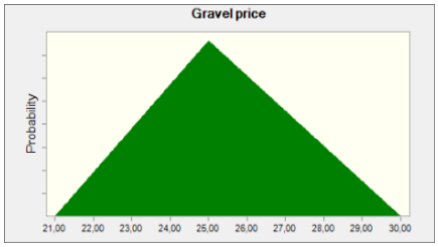
Triangular distribution with parameters(euro/liter):

Minimum	0,22
Likeliest	0,38
Maximum	0,62



Triangular distribution with parameters(euro/m3):

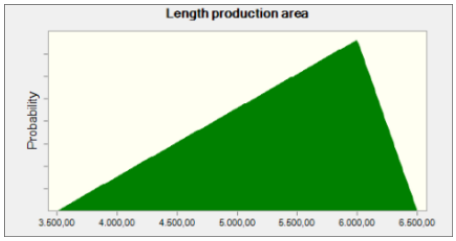
Minimum	21,00
Likeliest	25,00
Maximum	30,00



Distribution of length of production area

Triangular distribution with parameters(km):

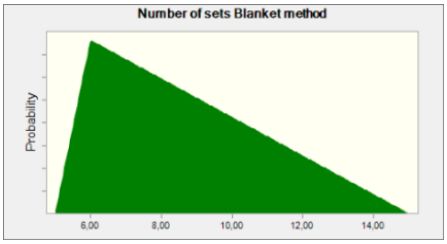
Minimum	3.500,00
Likeliest	6.000,00
Maximum	6.500,00



Distribution of number of sets equipment

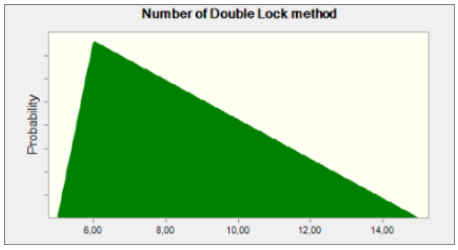
Triangular distribution with parameters:

Minimum	5,00
Likeliest	6,00
Maximum	15,00



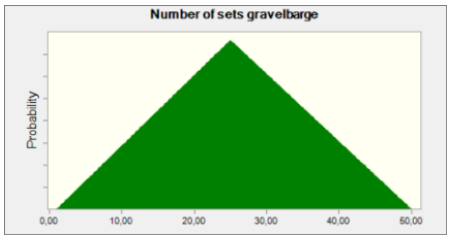
Triangular distribution with parameters:

Minimum	5,00
Likeliest	6,00
Maximum	15,00



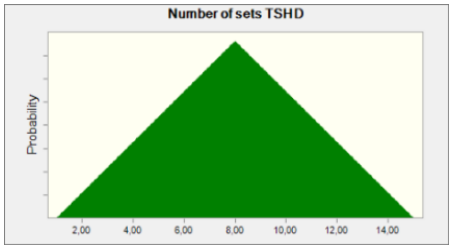
Triangular distribution with parameters:

Minimum	1,00
Likeliest	25,00
Maximum	50,00



Triangular distribution with parameters:

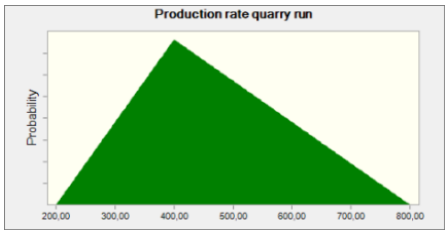
Minimum	1,00
Likeliest	8,00
Maximum	15,00



Distribution of production rate quarry and sailing distance

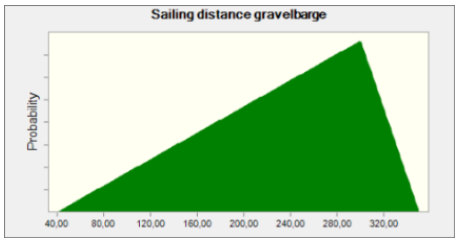
Triangular distribution with parameters(m3/h):

Minimum	200,00
Likeliest	400,00
Maximum	800,00



Triangular distribution with parameters(km):

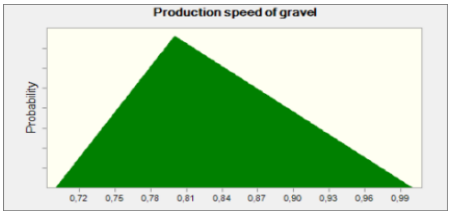
Minimum	40,00
Likeliest	300,00
Maximum	350,00



Distribution of production speed stone column technique

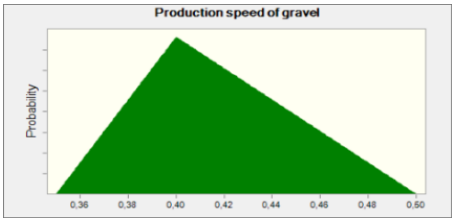
Triangular distribution with parameters(m3/min):

Minimum	0,70
Likeliest	0,80
Maximum	1,00



Triangular distribution with parameters(m3/min):

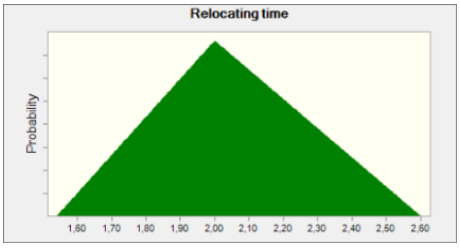
Minimum	0,35
Likeliest	0,40
Maximum	0,50



Distribution of relocating time

Triangular distribution with parameters:

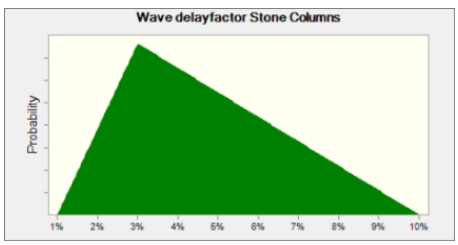
Minimum	1,54
Likeliest	2,00
Maximum	2,60



Distribution of wind delay factor

Triangular distribution with parameters:

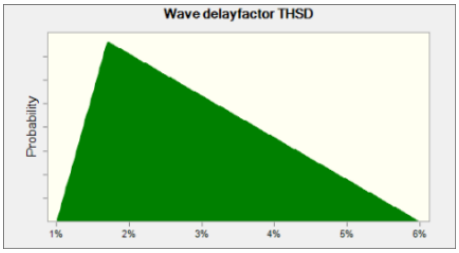
Minimum	1%
Likeliest	3%
Maximum	10%



Distribution Wave delay factor

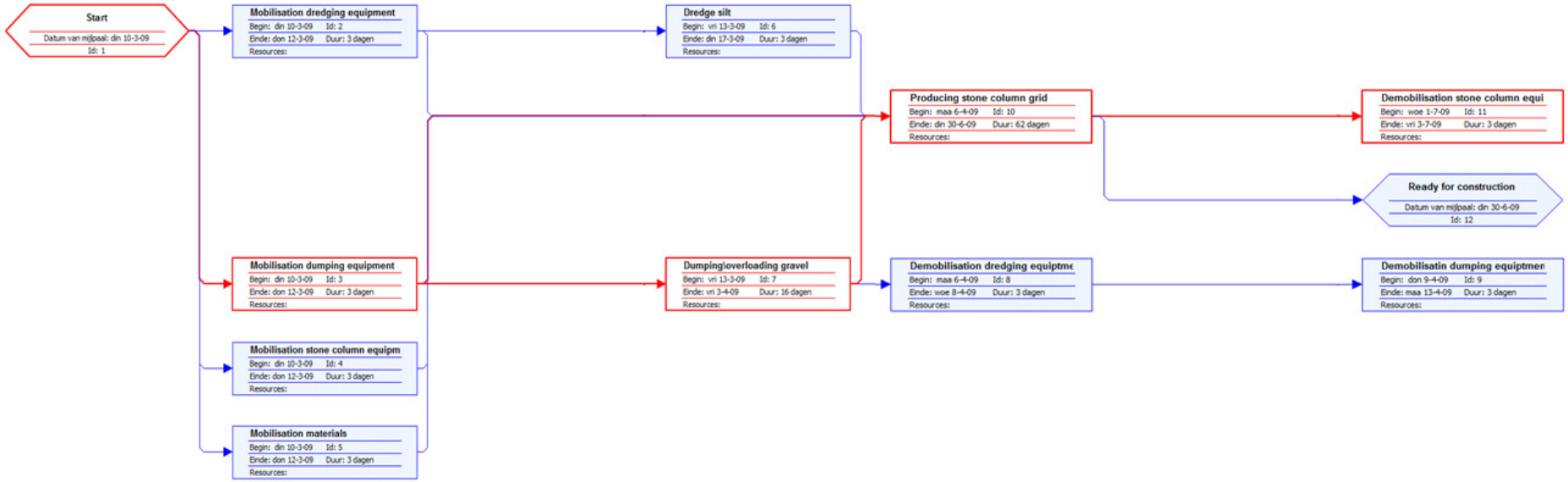
Triangular distribution with parameters:

Minimum	1%
Likeliest	2%
Maximum	6%



Appendix I Network diagram I

The activities given in red are the activities on the critical path of the schedule.



Appendix J Input table for risk and sensitivity analysis

First the input values for the risk analysis graphics are given:

Project time Blanket Method			
Time related	**laag**	**midden**	**hoog**
Stone Column length	162	195,50	229
C.T.C. distance	196	264,08	425
Custom service dumping equipment	196	210,63	237
Custom service Stone Column equipment	196	200,48	221
Custom service THSD	197	213,28	240
Stone Column diameter	109	162,07	200
EF gravel production	170	203,12	242
Length production area	128	174,09	205
Number of sets Blanket Method	99	150,88	212
Number of sets Double Lock Method	**196**	**196,00**	**196**
Number of sets Dumping equipment	189	200,08	241
Production rate quarry	194	195,59	198
Productionspeed Blanket Method	196	190,02	211
Productionspeed Double Lock Method	**196**	**196,00**	**196**
Relocation time	193	195,93	199
Sailing distance dumping equipment	187	193,08	197
Wavedelay factor	193	199,58	210
Winddelay factor	183	199,89	223
Totaal	90	185,09	355

Project time Double Lock Method			
Time related	**laag**	**midden**	**hoog**
Stone Column length	206	249,00	294
C.T.C. distance	250	315,00	548
Custom service dumping equipment	249	261,00	290

Custom service Stone Column equipment	249	249,00	271
Custom service THSD	250	264,00	293
Stone Column diameter	137	210,00	256
Length production area	165	227,00	262
Number of sets Blanket Method	**249**	**249,00**	**249**
Number of sets Double Lock Method	125	187,00	269
Number of sets Dumping equipment	241	249,00	306
Production rate quarry	248	249,00	251
Productionspeed Blanket Method	**249**	**249,00**	**249**
Productionspeed Double Lock Method	215	243,00	271
Relocation time	247	250,00	253
Sailing distance dumping equipment	244	248,00	250
Wavedelay factor	245	253,00	267
Winddelay factor	233	253,00	284
Total	106	222,99	433

Total Netto Costs Blanket Method

Cost related	**laag**	**midden**	**hoog**
Stone Column length	€ 239.191.017	€ 284.339.847	€ 330.186.816
C.T.C. distance	€ 285.780.373	€ 371.433.147	€ 555.685.297
Custom service dumping equipment	€ 290.654.915	€ 383.066.284	€ 526.961.435
Custom service Stone Column equipment	€ 285.323.871	€ 294.871.941	€ 309.355.959
Custom service THSD	€ 288.640.332	€ 351.162.104	€ 450.519.663
Stone Column diameter	€ 167.364.966	€ 239.477.976	€ 289.825.364
EF gravel production	€ 250.606.696	€ 294.542.286	€ 346.472.232
Fuelprice	€ 279.276.640	€ 286.008.169	€ 293.364.507
Gravelprice	€ 266.840.207	€ 286.768.816	€ 307.972.394
Length production area	€ 200.129.931	€ 257.256.858	€ 297.188.338
Number of sets Blanket Method	€ 282.868.695	€ 283.687.599	€ 285.046.534

Number of sets Double Lock Method	**€ 284.719.498**	**€ 284.719.498**	**€ 284.719.498**
Number of sets Dumping equipment	€ 279.762.417	€ 283.975.659	€ 287.277.315
Number of sets THSD	€ 279.633.753	€ 284.936.887	€ 291.349.737
Productionspeed Blanket Method	€ 277.185.796	€ 283.065.721	€ 288.826.196
Productionspeed Double Lock Method	**€ 284.719.498**	**€ 284.719.498**	**€ 284.719.498**
Sailing distance dumping equipment	€ 259.183.739	€ 276.352.745	€ 287.543.915
Wavedelay factor	€ 283.891.462	€ 285.688.646	€ 288.554.144
Totaal	€ 266.790.021	€ 474.969.729	€ 747.620.386

Total Netto Costs Double Lock Method

Cost related	laag	midden	hoog
Stone Column length	€ 245.064.007	€ 289.441.783	€ 334.457.380
C.T.C. distance	€ 289.733.152	€ 368.150.763	€ 506.614.154
Custom service dumping equipment	€ 294.817.599	€ 386.791.968	€ 530.667.045
Custom service Stone Column equipment	€ 289.764.053	€ 303.647.233	€ 324.352.504
Custom service THSD	€ 292.807.627	€ 353.621.745	€ 454.546.218
Stone Column diameter	€ 173.307.729	€ 245.305.350	€ 296.652.926
Fuelprice	€ 282.829.206	€ 290.247.711	€ 298.666.617
Gravelprice	€ 277.010.692	€ 290.175.166	€ 303.971.719
Length production area	€ 206.144.196	€ 263.000.203	€ 301.170.740
Number of sets Blanket Method	**€ 288.890.131**	**€ 288.890.131**	**€ 288.890.131**
Number of sets Double Lock Method	€ 288.470.721	€ 288.889.842	€ 289.578.564
Number of sets Dumping equipment	€ 283.189.242	€ 289.158.657	€ 292.982.395
Number of sets THSD	€ 283.745.475	€ 289.073.574	€ 295.702.447
Productionspeed Blanket Method	**€ 288.890.131**	**€ 288.890.131**	**€ 288.890.131**
Productionspeed Double Lock Method	€ 275.654.126	€ 286.193.812	€ 296.635.319
Sailing distance dumping equipment	€ 274.859.580	€ 284.629.166	€ 291.688.608
Wavedelay factor	€ 287.398.282	€ 290.879.457	€ 295.537.764
Totaal	€ 281.532.944	€ 487.017.774	€ 746.303.205

Second the input values for the sensitivity analysis graphics:

Project time Blanket Method							
Time related	**-20%**	**-10%**	**-5%**	**0**	**5%**	**10%**	**20%**
Stone Column length	161	178	187	196	205	212	230
C.T.C. distance	296	236	214	196	178	164	139
Custom service dumping equipment	196	196	196	196	196	196	196
Custom service Stone Column equipment	196	196	196	196	196	196	196
Custom service THSD	196	196	196	196	196	196	196
Stone Column diameter	133	163	178	196	213	232	272
EF gravel blanket	161	178	187	196	205	212	230
Length production area	158	176	186	196	205	214	234
Number of sets Blanket Method	230	211	203	196	189	171	152
Number of sets Double Lock Method	196	196	196	196	196	196	196
Number of sets Dumping equipment	200	198	197	196	195	194	193
Production rate quarry	197	196	196	196	196	196	195
Productionspeed Blanket Method	235	213	204	196	188	181	167
Productionspeed Double Lock Method	196	196	196	196	196	196	196
Relocation time	193	194	195	196	196	197	199
Sailing distance dumping equipment	193	195	195	196	196	197	198
Wavedelay factor	194	195	195	196	196	196	197
Winddelay factor	190	193	194	196	197	199	202
Totaal							

Project time Double Lock Method

Time related	-20%	-10%	-5%	0	5%	10%	20%
Stone Column length	204	226	238	249	261	272	295
C.T.C. distance	381	303	274	249	226	209	178
Custom service dumping equipment	249	249	249	249	249	249	249
Custom service Stone Column equipment	249	249	249	249	249	249	249
Custom service THSD	249	249	249	249	249	249	249
Stone Column diameter	168	207	227	249	273	297	350
Length production area	202	225	237	249	261	274	299
Number of sets Blanket Method	249	249	249	249	249	249	249
Number of sets Double Lock Method	294	270	259	249	240	217	193
Number of sets Dumping equipment	254	251	250	249	248	248	246
Production rate quarry	250	250	249	249	249	249	249
Productionspeed Blanket Method	249	249	249	249	249	249	249
Productionspeed Double Lock Method	302	273	260	249	239	230	214
Relocation time	246	248	249	249	250	251	252
Sailing distance dumping equipment	248	249	249	249	250	250	251
Wavedelay factor	248	248	249	249	250	250	251
Winddelay factor	242	245	247	249	251	253	257
Total							

Total Netto Costs Blanket Method							
Cost related	**-20%**	**-10%**	**-5%**	**0**	**5%**	**10%**	**20%**
Stone Column length	€ 237.875.713	€ 259.928.449	€ 272.338.606	€ 284.719.498	€ 297.071.297	€ 306.311.316	€ 330.890.962
C.T.C. distance	€ 413.036.329	€ 336.380.525	€ 307.926.711	€ 284.719.498	€ 260.355.264	€ 242.613.211	€ 210.622.900
Custom service dumping equipment	€ 284.719.498	€ 284.719.498	€ 284.719.498	€ 284.719.498	€ 284.719.498	€ 284.719.498	€ 284.719.498
Custom service Stone Column equipment	€ 284.719.498	€ 284.719.498	€ 284.719.498	€ 284.719.498	€ 284.719.498	€ 284.719.498	€ 284.719.498
Custom service THSD	€ 284.719.498	€ 284.719.498	€ 284.719.498	€ 284.719.498	€ 284.719.498	€ 284.719.498	€ 284.719.498
Stone Column diameter	€ 198.549.907	€ 239.913.263	€ 260.295.555	€ 284.719.498	€ 306.949.488	€ 332.890.208	€ 387.108.363
EF gravel blanket	€ 237.875.713	€ 259.928.449	€ 272.338.606	€ 284.719.498	€ 297.071.297	€ 306.311.316	€ 330.890.962
Fuelprice	€ 281.243.919	€ 282.981.487	€ 283.850.376	€ 284.719.498	€ 285.588.169	€ 286.457.047	€ 288.194.852
Gravelprice	€ 255.377.467	€ 270.048.482	€ 277.383.990	€ 284.719.498	€ 292.055.006	€ 299.390.514	€ 314.061.529
Length production area	€ 237.021.088	€ 259.367.633	€ 272.060.593	€ 284.719.498	€ 297.071.297	€ 306.854.195	€ 333.495.235
Number of sets Blanket Method	€ 285.497.127	€ 284.943.417	€ 284.774.675	€ 284.719.498	€ 284.523.149	€ 284.032.897	€ 283.465.843
Number of sets Double Lock Method	€ 284.719.498	€ 284.719.498	€ 284.719.498	€ 284.719.498	€ 284.719.498	€ 284.719.498	€ 284.719.498
Number of sets Dumping equipment	€ 284.403.161	€ 285.141.702	€ 285.075.876	€ 284.719.498	€ 284.072.153	€ 283.133.432	€ 283.793.703
Number of sets THSD	€ 282.871.986	€ 282.871.986	€ 282.871.986	€ 282.871.986	€ 282.871.986	€ 282.871.986	€ 282.871.986
Productionspeed Blanket Method	€	€	€	€	€	€	€

Productionspeed Double Lock	295.282.300 €	289.369.565 €	286.916.658 €	284.719.498 €	282.506.408 €	280.556.795 €	276.620.403 €
Method	284.719.498 €	284.719.498 €	284.719.498 €	284.719.498 €	284.719.498 €	284.719.498 €	284.719.498 €
Sailing distance dumping equipment	276.230.807 €	281.892.509 €	281.892.509 €	284.719.498 €	284.719.498 €	287.543.915 €	290.365.764 €
Wavedelay factor	284.167.723 €	284.443.735 €	284.443.735 €	284.719.498 €	284.719.498 €	284.719.498 €	284.995.012 €
Totaal							

Total Netto Costs Double Lock Method							
Cost related	**-20%**	**-10%**	**-5%**	**0**	**5%**	**10%**	**20%**
Stone Column length	244.404.583 €	265.339.231 €	277.329.539 €	288.890.131 €	300.769.900 €	312.228.799 €	335.359.133 €
C.T.C. distance	410.429.945 €	343.266.002 €	313.689.473 €	288.890.131 €	265.631.057 €	248.997.577 €	218.503.457 €
Custom service dumping equipment	288.890.131 €	288.890.131 €	288.890.131 €	288.890.131 €	288.890.131 €	288.890.131 €	288.890.131 €
Custom service Stone Column equipment	288.890.131 €	288.890.131 €	288.890.131 €	288.890.131 €	288.890.131 €	288.890.131 €	288.890.131 €
Custom service THSD	288.890.131 €	288.890.131 €	288.890.131 €	288.890.131 €	288.890.131 €	288.890.131 €	288.890.131 €
Stone Column diameter	206.757.312 €	246.571.854 €	265.970.295 €	288.890.131 €	312.843.470 €	337.072.217 €	390.454.332 €
Fuelprice	285.027.684 €	286.958.636 €	287.924.117 €	288.890.131 €	289.855.347 €	290.820.817 €	292.752.058 €
Gravelprice	269.550.536 €	279.220.334 €	284.055.232 €	288.890.131 €	293.725.030 €	298.559.929 €	308.229.727 €
Length production area							

	243.627.918 €	264.958.825 €	276.953.292 €	288.890.131 €	300.769.900 €	312.957.172 €	338.227.948 €
Number of sets Blanket Method	288.890.131 €	288.890.131 €	288.890.131 €	288.890.131 €	288.890.131 €	288.890.131 €	288.890.131 €
Number of sets Double Lock Method	289.434.506 €	289.314.536 €	289.079.942 €	288.890.131 €	288.791.573 €	288.626.148 €	288.510.301 €
Number of sets Dumping equipment	288.963.859 €	288.398.034 €	288.788.952 €	288.890.131 €	288.701.155 €	291.313.175 €	289.775.052 €
Number of sets THSD	287.045.961 €	287.045.961 €	287.045.961 €	287.045.961 €	287.045.961 €	287.045.961 €	287.045.961 €
Productionspeed Blanket Method	288.890.131 €	288.890.131 €	288.890.131 €	288.890.131 €	288.890.131 €	288.890.131 €	288.890.131 €
Productionspeed Double Lock Method	308.160.547 €	297.729.926 €	292.965.298 €	288.890.131 €	285.150.485 €	281.756.134 €	275.654.126 €
Sailing distance dumping equipment	286.089.113 €	288.890.131 €	288.890.131 €	288.890.131 €	291.688.608 €	291.688.608 €	294.484.546 €
Wavedelay factor	288.517.669	288.517.669	288.890.131	288.890.131	289.262.261	289.262.261	289.634.058
Totaal							