Reliability of Quay Walls

Calibration of partial safety factors for parameters in quay wall design by probabilistic Finite Element calculations

Appendices

Herm-Jan Wolters
Section Hydraulic Engineering
Faculty of Civil Engineering and Geosciences
Delft University of Technology
7 September 2012

MSc Thesis committee:

Dr. ir. K.J. Bakker
Hydraulic Engineering / WAD43 BV

Dr. ir. R.B.J. Brinkgreve
Geo-Engineering / PLAXIS BV

Dr. ir. J.G. de Gijt
Hydraulic Engineering / GW Rotterdam

T. Schweckendiek, MSc
Hydraulic Engineering / Deltares

Prof. drs. ir. J.K. Vrijling
Hydraulic Engineering

Prof. ir. A.C.W.M. Vrouwenvelder
Design and Construction / TNO

Index

A. Appendix - FORM example

As an example of FORM a calculation with two stochastic variables is elaborated here. In the calculation the reliability of a steel bar and the influence coefficients of the parameters are determined. The characteristics of the steel are presented in Table A-1. d is the diameter of the bar in mm and σ the yield stress in N/mm^2.

X_i	μ_{xi}	σ_{xi}
d	30	3
σ	290	25

Table A-1 parameters steel bar

The Limit State is described by failure of the bar when the force is larger than 100 kN. The reliability function is given by $Z = \frac{\pi d^2}{4}\sigma - 100000$

At first the 'design point' is set to d*=30 mm and σ*=290 Nmm^2. The partial derivatives need to be calculated:

$$\frac{\partial Z(X_i^*)}{\partial X_1} \rightarrow \begin{matrix} \frac{\partial Z(d^*)}{\partial d} = \frac{\pi d^* \sigma^*}{2} = \frac{\pi \cdot 30 \cdot 290}{2} \approx 13666 \\ \frac{\partial Z(\sigma^*)}{\partial \sigma} = \frac{\pi d^{*2}}{4} = \frac{\pi \cdot 30^2}{4} \approx 707 \end{matrix}$$

The influence factors now follow from:

$$\alpha_i = -\frac{\frac{\partial}{\partial X_i} Z(\vec{X}^*)\sigma_{xi}}{\sqrt{\sum_{j=1}^{n}(\frac{\partial}{\partial X_j} Z(\vec{X}^*)\sigma_{xj})^2}} = -\frac{\frac{\partial}{\partial X_i} Z(\vec{X}^*)\sigma_{xi}}{\sigma_Z} \rightarrow \begin{matrix} \alpha_d = -\frac{13666 \cdot 3}{\sqrt{(13666 \cdot 3)^2 + (707 \cdot 25)^2}} \approx -0.91 \\ \alpha_\sigma = -\frac{707 \cdot 25}{\sqrt{(13666 \cdot 3)^2 + (707 \cdot 25)^2}} \approx -0.39 \end{matrix}$$

And the mean value of Z:

$$\mu_Z = Z(X_i^*) + \Sigma(\frac{\partial Z(X_i^*}{\partial X_i^*}(X_i^* - \mu_{Xi})) = \frac{\pi d^{*2}\sigma^*}{4} - 100000 \approx 1.05 \cdot 10^5$$

The reliability index follows from:

$$\beta = \frac{\mu_Z}{\sigma_Z} = \frac{1{,}05 \cdot 10^5}{\sqrt{(13666 \cdot 3)^2 + (707 \cdot 25)^2}} \approx 2.36$$

The new design point values follow from:

$$X_i^* = \mu_{Xi} + \alpha_i \beta \sigma_{xi} \rightarrow \begin{matrix} d^* = 30 - 0.91 \cdot 2{,}36 \cdot 3 \approx 23.6mm \\ \sigma^* = 290 - 0{,}39 \cdot 2{,}36 \cdot 25 \approx 267.0 N/mm^2 \end{matrix}$$

These are the input value for the next calculation. The calculations are further executed in Table A-2.

Iteration 1									
X_i	μ	σ_x	X_i^*	$\frac{\partial Z(X_i^*)}{\partial X_i}$	$\frac{\partial Z(X_i^*)}{\partial X_i}\sigma_x$	$(\frac{\partial Z(X_i^*)}{\partial X_i}\sigma_x)^2$	α_i		
d	30	3	30.0	13666	40998	1680818304	-0.92	σ_z	44644
σ	290	25	290.0	707	17671	312280452	-0.40	μ_z	104989
								β	2.35
Iteration 2									
d	30	3	23.5	9855	29564	874054762	-0.94	σ_z	31497
σ	290	25	266.7	435	10863	118003744	-0.34	μ_z	89858
								β	2.85
Iteration 3									
d	30	3	22.0	9158	27473	754758364	-0.95	σ_z	29061
σ	290	25	265.4	379	9474	89762893	-0.33	μ_z	83471
								β	2.87
Iteration 4									
d	30	3	21.9	9151	27454	753749086	-0.95	σ_z	29012
σ	290	25	266.6	375	9378	87938109	-0.32	μ_z	83328
								β	2.87
Iteration 5									
d	30	3	21.8	9155	27465	754331433	-0.95	σ_z	29020
σ	290	25	266.8	375	9371	87809124	-0.32	μ_z	83351
								β	2.87

Table A-2 FORM steel bar calculations (5 iterations)

It can be concluded that a suited design point is a diameter d = 21.8 mm and a yield stress of σ = 266.8 N/mm^2. This corresponds to a reliability index of β=2.87. The probability of failure can be determined:

$$P_f = \Phi(2.87) = 0.998$$

B. Appendix - Method Bakker

This appendix describes Method Bakker, which can be used to make probabilistic Finite Element Method (FEM) calculations.

B.1 Theoretical approach

Bakker (2005) explains his method in an article about river dikes strengthened with structural elements. He notes that the calculations of failure probabilities of these dikes with level II probabilistic models is a time consuming and complex task, because of the many uncertainties that must be considered. The method Bakker, however, requires only a small number of FEM calculations using φ-C reductions. The probability of failure can be determined by the safety factors following from these calculations, the number of independent soil layers and the statistical distributions of the different variables (i.e. shear strength of soil, wall friction, water levels, etc.). The basic assumption is that geotechnical failure can be described with a Coulomb friction criterion: $\tau = C + \sigma_{\perp} \tan \varphi$

Furthermore it is assumed that failure can be described by an undrained shear strength C_u (which supposes that water in soil is incompressible in proportion to the stiffness of the soil skeleton):

$C_u(C,\varphi) = \sigma_p^{'} \sin \varphi + C \cos \varphi$ with mean effective stress: $\sigma_p^{'} = 0.5\sigma_v^{'}(1 + K_0)$.

The following relationship exists:

$$\frac{Cu_a}{Cu_c} = \sqrt{\frac{Fv_v^{\,2} + \tan^2 \varphi_a}{1 + \tan^2 \varphi_a}}$$

As FEM calculations can not handle autocorrelation functions in order to model spatial variability's and averaging of spatial fluctuations, Bakker assumes that fluctuations of shear strength in a vertical direction will be completely averaged within the volume affected by the analysis, whereas averaging of fluctuations in horizontal direction will be ignored. The standard deviation of the shear strength of a soil unit or layer may then be given by:

$$\sigma_{\ddot{c}} = \sigma_{\hat{c}} \sqrt{(1 - a) + \frac{1}{n}}$$

Where $\sigma_{\hat{c}}$ is the standard deviation from shear tests, n is the number of shear tests and a the ratio between the local point variation and the total regional variation. The uncertainties of the other variables are assumed to be normal distributed.

The stability factor of soil failure can be described by $Fs = \dfrac{\sum_{i=1}^{n} w_i Cu_i}{\sum_{i=1}^{n} w_i Cu_{c,i}}$

Where W_i are the weight factors, depending on size and incremental strains of the particular soil layer (sum equals 1).

Fs must be linearised in a design point S* $Fs = 1 + K \sum_{i=1}^{n} w_i (Cu_i - Cu_{c,i})$

With $K \approx (\sum_{i=1}^{n} w_i Cu_{c,i})^{-1}$

Now the Soil failure function can be defined as: $Z_g = Fs - 1$

With mean value and standard deviation:

$$\mu(Z_g) = K\sum_{i=1}^{n} w_i(\mu(Cu_i) - Cu_{c,i}); \sigma(Z_g) = K\sqrt{\sum_{i=1}^{n} w_i^{\,2}\sigma^2(Cu_i)}$$

The β calculated from deterministic parameter values, except for C and φ: $\beta^0_{g|MHW} = \frac{\mu(Z_g)}{\sigma(Z_g)}$

When w_i are unknown, they must be considered as uncertain parameters. For every partition of w_i (sum =1) a reliability index and failure probability index can be determined. The best estimate for $Pf_g^{0}{}_{|MHW}$ is the average of these. To determine this Bakker uses a Monte-Carlo simulation.

Influence on the reliability index from uncertainties in groundwater levels, geometry, wall friction, external loads and other uncertainties can be taken into account with the following equation:

$$\beta_{g|MHW} = \frac{\beta^0_{g|MHW}}{\sqrt{1 + \sum_{i=1}^{n}(\frac{\partial\beta^0_{g|MHW}}{\partial x_i})^2\sigma^2(x_i)}}$$

Furthermore sheet pile failure can occur which is described by the Limit State Function: $Z_d = (f_y - f_{y,d}(Fs)) = 0$

$f_{y,d}$(FS) can be determined from a φ-C reduction or from a number of calculations with immediately reduced shear strength parameters.

$$Pf_{d|MHW} \mid Fs = \Phi(-\beta_{d|MHW} \mid Fs) = \Phi(-\frac{\mu(f_y) - f_{y,d}(Fs)}{\sigma(f_y)})$$

In the case of an anchor, a comparable expression exists for anchor failure.

The failure probability of the structure in total can be defined as: $Pf_{c|MHW} = Pf_{g|MHW} + Pf_{d|MHW} \mid Fs \geq 1$

Bakker concludes his article with saying that with his method it is possible to calculate an estimate of the reliability index of a dike strengthened with structural elements on a comparatively quick and easy way. The advantage of the method is the reduction in the number of FEM calculations and that it only needs information that can be acquired easily and it is understandable for practical geotechnical engineers.

B.2 Practical implementation

Bakker implemented his method in a number of spreadsheets. The work approach of the method is more practically described in the 'Technisch Rapport Kistdammen en Diepwanden in Waterkeringen' (TAW, 2004). Furthermore, Kanning (2005) did research on slope stability of dikes. He used the method Bakker to calculate partial safety factors for the involved parameters. It can be questioned whether the method is useful in quay wall design as it focuses on soil mechanical failure.

C. Appendix - Monte Carlo simulation

The PLAXIS input variables are not always equal to the basic random variables. For instance, EA is required as input for anchor axial stiffness. However the basic variables are the anchor diameter, Da, and the Elasticity modulus, E. These basic random variables have their own coefficient of variation (CoV) and distribution.

To obtain the correct CoV's for the PLAXIS input variables, a Monte Carlo simulation can be executed. Basically, this requires a sampling of a number of parameter values from the distribution of the first parameter and combining this with the sampled parameters from the distribution of the second parameter.

Taking the mean and standard deviation of this combined vector of parameter values, gives an estimation of the mean and standard deviation of the PLAXIS input variables. The more samples are taken, the more accurate the result.

For this research a million samples are taken of each basic random variable. As an example the determination of PLAXIS input variable EA of the anchor is taken. The MatLab script to obtain this is given below (The values used in this example are fictive).

```
n=1e6;                      %           Number of calculations

%Anchor
Emu_a=2.1*10^8;             %[kN/m2]    mean E-modulus steel anchor
Esig_a=0.03*Emu_a;          %[kN/m2]    standard deviation

length=29-0.5*12;           %[m]        length anchor

fymu_a=355*10^3;            %[kN/m2]    yield stress steel
fysig_a=0.07*fymu_a;        %[kN/m2]    standard deviation

Dmu_a=0.053;                %[m]        mean diameter anchor
Dsig_a=0.07*Dmu_a;          %[m]        standard deviation

%CREATE NORMAL DISTRIBUTIONS
E_a=normrnd(Emu_a,Esig_a,n,1);
fy_a=normrnd(fymu_a,fysig_a,n,1);
D_a=normrnd(Dmu_a,Dsig_a,n,1);

%PLAXIS INPUT PARAMETERS

%Anchor
%EA anchor
A_a=1/4.*pi.*D_a.^2;         %[m2]
EA_a=E_a.*A_a./length;       %[kN/m]

%Fmax anchor
Fmax_a=fy_a.*A_a;            %[kN/m]

%PROB PLAXIS INPUT
mean_values=[mean(EA_a),mean(Fmax_a)];
standard_deviations=[std(EA_a),std(Fmax_a)];
variation_coefficients=standard_deviations./mean_


%CORRELATION MATRIX
%combi-wall parameters
correlation_anchor=corrcoef([Ea_a,Fmax_a]);
```

The plots of the parameters are given in Figure C-1, which shows that the mean value of the Axial stiffness over anchor length equals 20000 kN/m and the standard deviation is 1400 kN/m. This implies a CoV of 0.07.

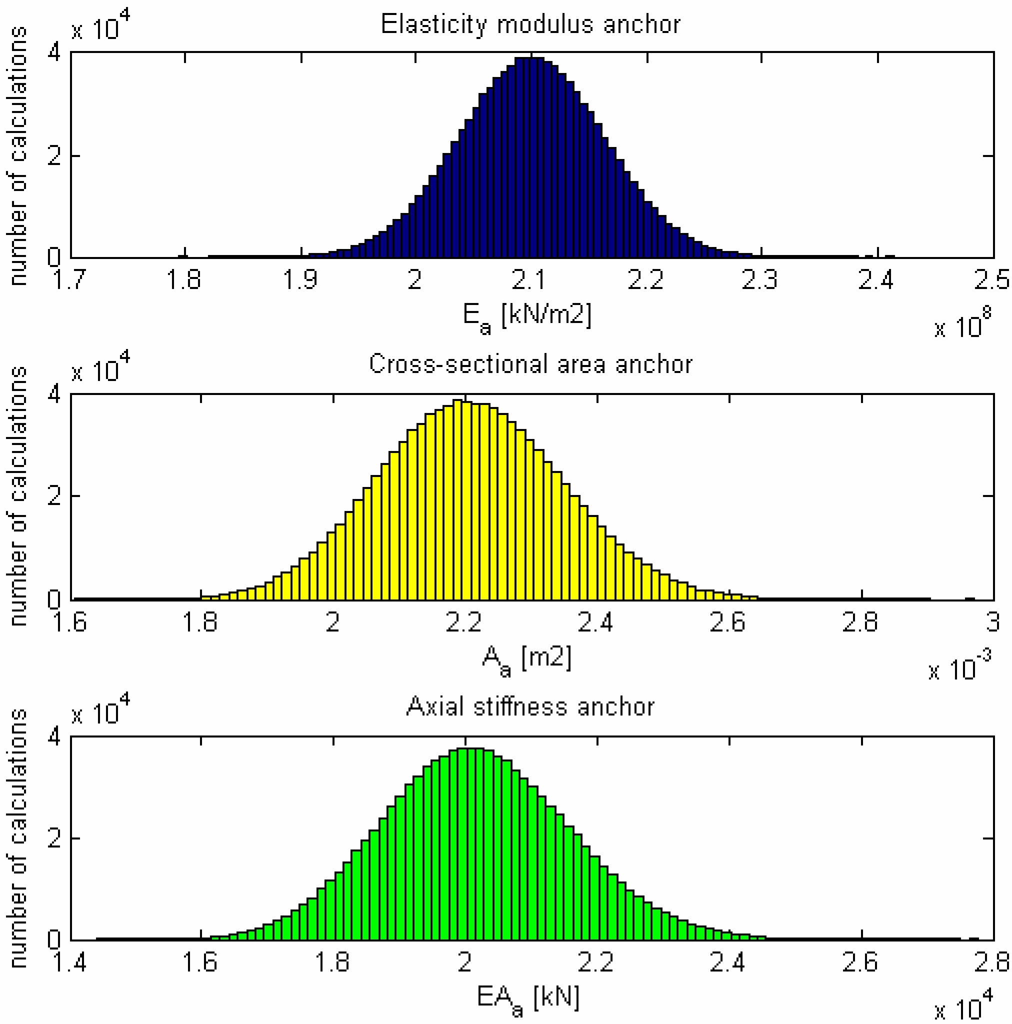

Figure C-1 probability density plots random variables

C.1 Correlations

With the same simulations correlations can be found between PLAXIS input parameters. For example the relation between the axial stiffness EA_a of the anchor and the maximum anchor force $Fmax_a$. The correlation of 0.61 is clearly visible in Figure C-2.

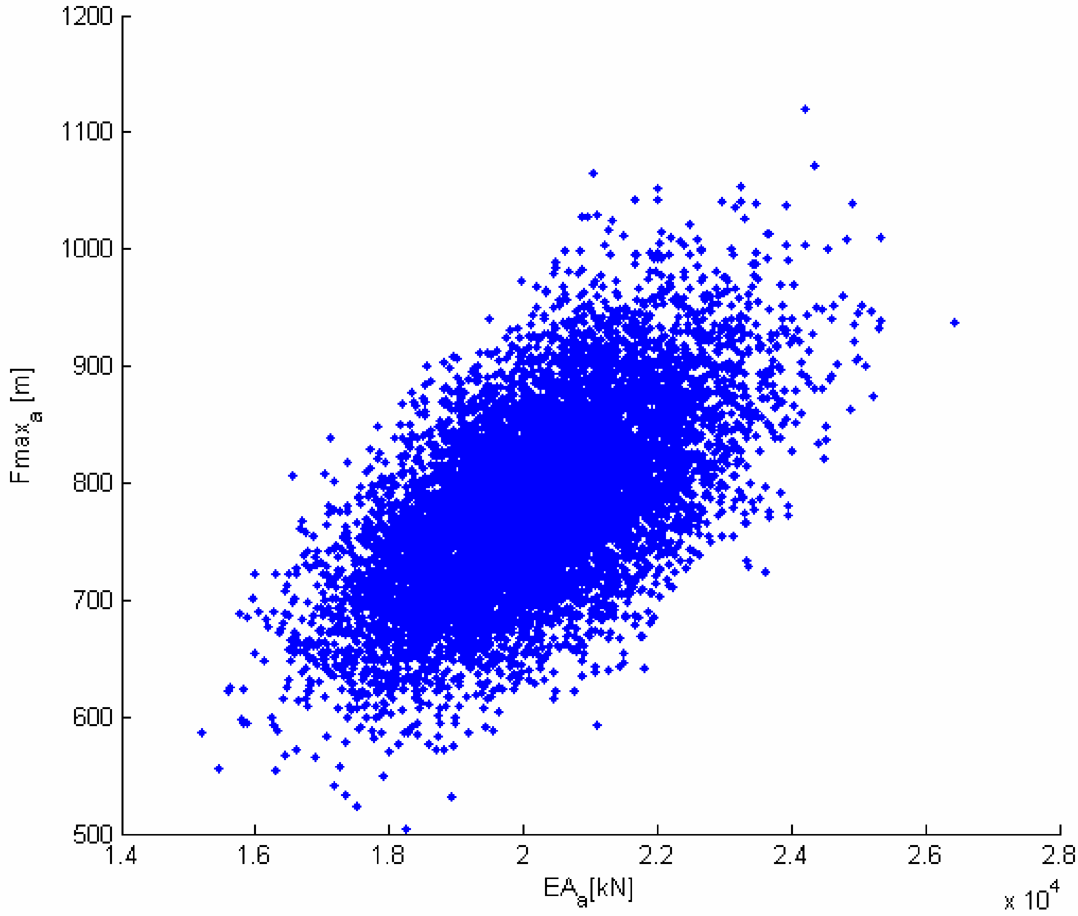

Figure C-2 Correlation between $Fmax_a$ and EA_a

D. Appendix - PLAXIS input parameters

Prob2B requires different input for plate elements than the PLAXIS user interface. Therefore the cross-section of the sheet-pile needs to be transformed into a rectangular cross-section with thickness d and an equivalent Elasticity modulus E_{eq}. The equivalent stiffness is than visible in the following expressions of bending stiffness and axial stiffness of the sheet-pile:

$EI = E_{eq}\dfrac{bd^3}{12}$ and $EA = E_{eq}bd$

From here an expression for d can be found:

$$d = \frac{12EI}{Ebd^2} = \frac{EA}{Eb} \rightarrow d = \sqrt{12\frac{I}{A}}$$

And for the equivalent Elasticity modulus:

$E_{eq} = \dfrac{EA}{bd} = \dfrac{EA}{\sqrt{12\frac{I}{A}}}$ (with b=1m)

The toolbox uses the equivalent shear modulus G_{eq}

$G_{eq} = \dfrac{E_{eq}}{2(1+\nu)} = \dfrac{EA}{2d(1+\nu)}$ (with v is Poisson's ratio)

E. Appendix - Z-convergence

In this appendix two figures are presented. Figure E-1 shows a convergent calculation with respect to the Z-criterion and Figure E-2 shows a non-convergent calculation. Although the parameters used are different from the real calculations, the shapes of the graphs show clearly the difference between the two types of calculations.

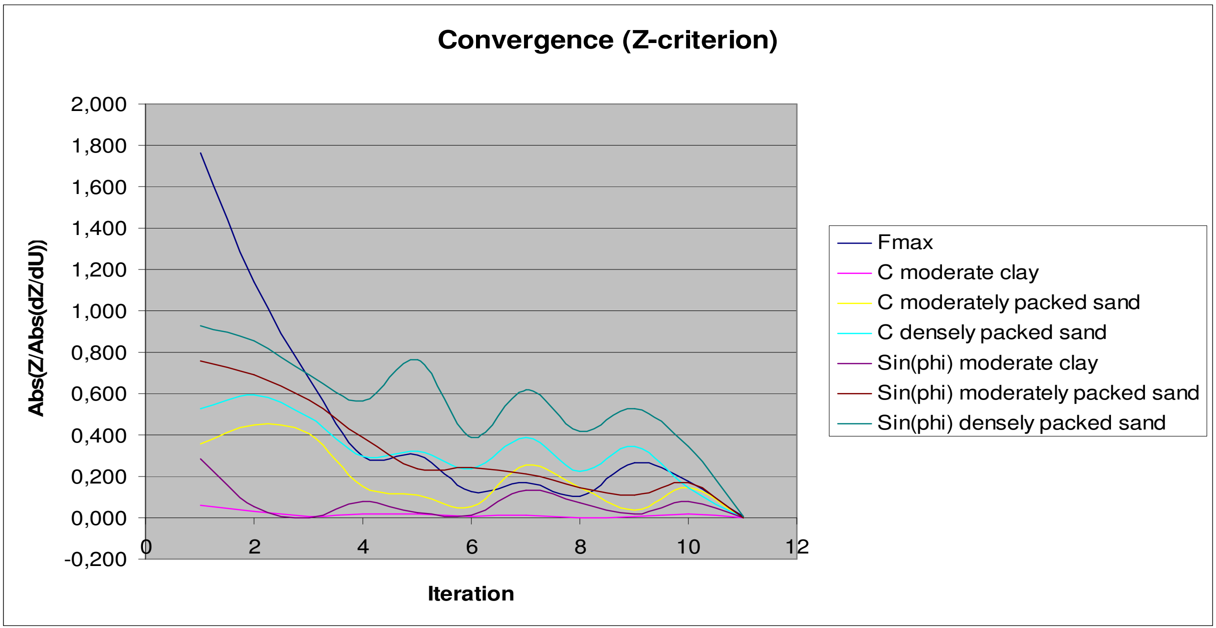

Figure E-1 convergent calculation (Z-criterion)

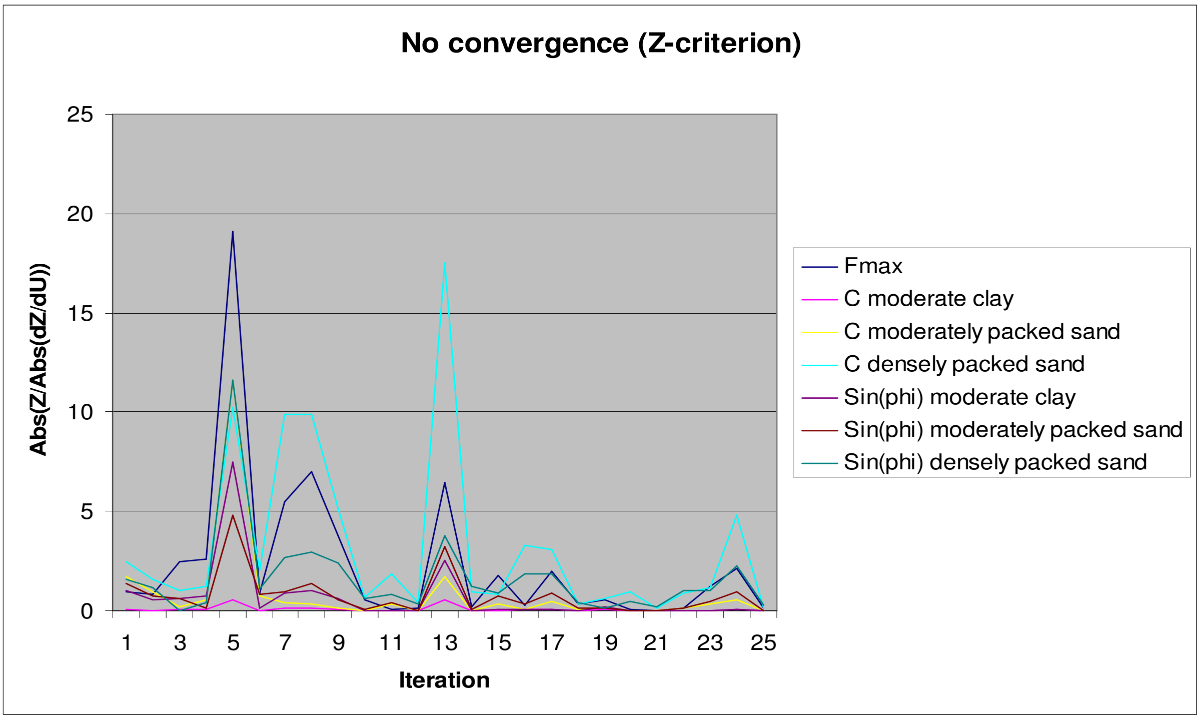

Figure E-2 non-convergent calculation (Z-criterion) max. 25 iterations

F. Appendix - MatLab code probabilistic Blum calculations

Below the MatLab code is given to perform a Blum calculation. This code is based on the code presented by Verruijt (2010) and used to make probabilistic calculations as well.

```
da = 2.0;                     %anchor depth
n = 4;                        %number of layers
Z = 0;                        %layer upper limit
nn = 1000; z = zeros(nn+1,1); %depth intervals
D = [10,2,3,50];              %layer thicknesses
cl = [0,0,10,1];              %cohesion values
cr = [1,10,10,1];             %cohesion values
phi = [32.5,22.5,22.5,35];    %Internal angle of friction

for i=1:n
Ka (1,i) = KotterKa(phi(i));  %Active soil pressure coefficient (Kötter)
Kp (1,i) = KotterKp(phi(i));  %Passive soil pressure coefficient (Kötter)

end

Gdl = [0,0,16,20];            %dry volumetric soil weight, excavation side
Gwl = [10,10,16,20];          %wet volumetric soil weight, excavation side
Wl = [-6.0,-6.0,-6.0,-5.0];   %groundwater head excavation side
Gdr = [17,16,16,20];          %dry volumetric soil weight, load side
Gwr = [19,16,16,20];          %wet volumetric soil weight, load side
Wr = [-4.0,-4.0,-4.0,-5.0];   %groundwater head, load side
GW = 10;                      %volumetric weight of water [kN/m3]
sur = 30;                     %surcharge load [kPa]


for i = 1:n                   %layer upper limits
    Z(i+1) = Z(i)-D(i);
end

dz = abs(Z(n+1))/nn;          %depth intervals
j=2;                          %counter soil layers (layer=j-1)

GL=zeros(nn+1,1); GR=zeros(nn+1,1); pl=zeros(nn+1,1); pr=zeros(nn+1,1);
Gdl(n+1)=Gdl(n); Gdr(n+1)=Gdr(n); Gwl(n+1)=Gwl(n); Gwr(n+1)=Gwr(n);
Wl(n+1)=Wl(n); Wr(n+1)=Wr(n); Kp(n+1)=Kp(n); Ka(n+1)=Ka(n); cl(n+1)=cl(n);
cr(n+1)=cr(n);
sigzzl=zeros(nn+1,1); sigzzr=zeros(nn+1,1); sigzzr(1,1) = sur;


%calculation loop for each slice (slice=i-1)
for i = 2:(nn+1)
    z(i) = z(i-1)-dz;
    if z(i)<Z(j)              %identification soil layer
        j=j+1;
    end

    %volumetric weights and pore pressures, excavation side
    if z(i)>Wl(j-1)
        Gl(i,:) = Gdl(1,j-1);
        pl(i) = 0;
    else
        Gl(i,:) = Gwl(1,j-1);
        pl(i) = -GW*(z(i)-Wl(1,j-1));
```

```
    end

    %volumetric weights and pore pressures, load side
    if z(i)>Wr(j-1)
        Gr(i,:) = Gdr(1,j-1);
        pr(i) = 0;
    else
        Gr(i,:) = Gwr(1,j-1);
        pr(i) = -GW*(z(i)-Wr(1,j-1));
    end

    %total vertical stress
    sigzzl(i) = sigzzl(i-1)+dz*Gl(i);
    sigzzr(i) = sigzzr(i-1)+dz*Gr(i);

    %effective vertical stress
    sigeffzzl(i,1) = sigzzl(i)-pl(i);
    sigeffzzr(i,1) = sigzzr(i)-pr(i);

    %effective horizontal stress
    sigeffxxl(i,1) = Kp(j-1)*sigeffzzl(i,1)+2*cl(j-1)*sqrt(Kp(j-1));
    if Ka(j-1)*sigeffzzr(i,1) > 2*cr(j-1)*sqrt(Ka(j-1))
        sigeffxxr(i,1) = Ka(j-1)*sigeffzzr(i,1)-2*cr(j-1)*sqrt(Ka(j-1));
    else
        sigeffxxr(i,1) = 0;
    end

    %total horizontal stress
    sigxxl(i,1) = sigeffxxl(i,1)+pl(i);
    sigxxr(i,1) = sigeffxxr(i,1)+pr(i);

    %horizontal stress differences
    F(i,1) = sigxxr(i,1)-sigxxl(i,1);
end

%auxiliar shear forces and moments
Q = zeros(nn+1,1); M= zeros(nn+1,1);
j=0;
for i = 2:(nn+1)
    FF(i,1) = (F(i)+F(i-1))*dz/2; if (i-1)*dz < da; j=i; end
    Q(i) = Q(i-1)-FF(i); M(i) = M(i-1)+(Q(i)+Q(i-1))*dz/2;
end

%counter and convergence criterion
NH=nn+2; UA=1; P=zeros(nn+1,1); U=zeros(nn+1,1);
while UA > 0
    NH = NH-1; HT = (NH-1)*dz;
    T = -M(NH)/(HT-da);             %estimate of the anchor force
    P(NH) = 0; U(NH) = 0;
    for k = (NH-1):(-1):j
        M1 = M(k)+T*(k*dz-da);
        M2 = M(k+1)+T*(k*dz+dz-da);
        P(k) = P(k+1)+M1+M2;
        U(k) = U(k+1)-P(k)-P(k+1);
    end
    UA = U(j);

end

NH = NH+1;
```

```
HT = NH *dz;                        %sheet pile length
```

```
T = -M(NH)/(HT-da);                 %anchor force
```

```
%real moments and shear forces
Qr = zeros(NH,1); Mr = zeros(NH,1); zr = zeros(NH,1);
for i=1:j
    zr(i) = z(i);
    Qr(i) = Q(i);
    Mr(i) = M(i);
end
for i=j:NH
    zr(i) = z(i);
    Qr(i) = Q(i)+T;
    Mr(i) = M(i)+T*(i*dz-da);
end
```

```
maxM = max(Mr)                      %maximum bending moment
```

G. Appendix - Results Blum calculations (benchmark 1)

This appendix describes the results of the Blum calculations for benchmark 1. The results are presented per failure mechanism.

G.1.1 Results anchor failure

The obtained reliability index for anchor failure is β = 4.49. The influence factors are given in Table G-1 and visualised in percentages (α_i^2*100) in Figure G-1.

Parameter	α
$\varphi_{moderately\ packed\ sand}$	0.88
$\varphi_{moderate\ clay}$	0.07
$\varphi_{densely\ packed\ sand}$	0.16
$C_{moderate\ clay}$	0.11
$\gamma_{sat,moderate\ clay}$	-0.19
$\gamma_{sat,moderately\ packed\ sand}$	-0.01
$\gamma_{sat,densely\ packed\ sand}$	0.02
$\gamma_{unsat,moderately\ packed\ sand}$	-0.01
Water level (outside)	0.08
Water level (ground)	-0.05
Surcharge load	0.06
Retaining height	0.05
$f_{y,steel}$	0.28
D_a	0.24

Table G-1 Influence factors anchor failure with Blum

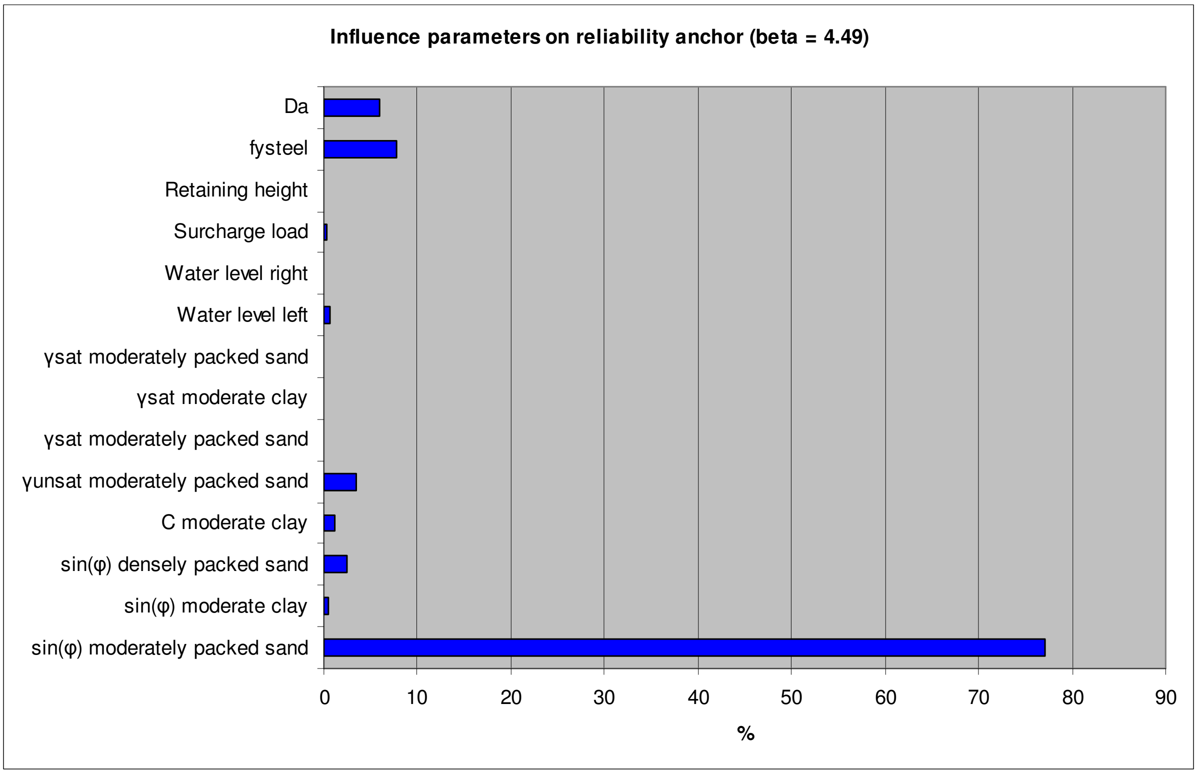

Figure G-1 Influence in % from parameters on reliability calculation Blum anchor failure

It is clear that the additional parameters retaining height, water levels and surcharge hardly influence the reliability of the structure with respect to anchor failure. This shows that it is no problem that these parameters cannot be included in the PLAXIS calculations for the LS anchor failure.

G.1.2 Results wall failure

The obtained reliability index for wall failure in bending is β = 3.15. The influence factors are given in Table G-2 and visualised in percentages in Figure G-2.

Parameter	α
$\varphi_{moderate\ clay}$	0.19
$\varphi_{moderately\ packed\ sand}$	0.19
$\varphi_{densely\ packed\ sand}$	0.85
$C_{moderate\ clay}$	0.32
$\gamma_{sat,moderate\ clay}$	-0.10
$\gamma_{sat,moderately\ packed\ sand}$	-0.01
$\gamma_{sat,densely\ packed\ sand}$	0.05
$\gamma_{unsat,moderately\ packed\ sand}$	0.10
Water level (outside)	0.20
Water level (ground)	-0.04
Surcharge load	0.09
Retaining height	0.13
$W_{AZ36\text{-}700N}$	0.08
$f_{y,steel}$	0.14

Table G-2 Influence factors wall failure with Blum

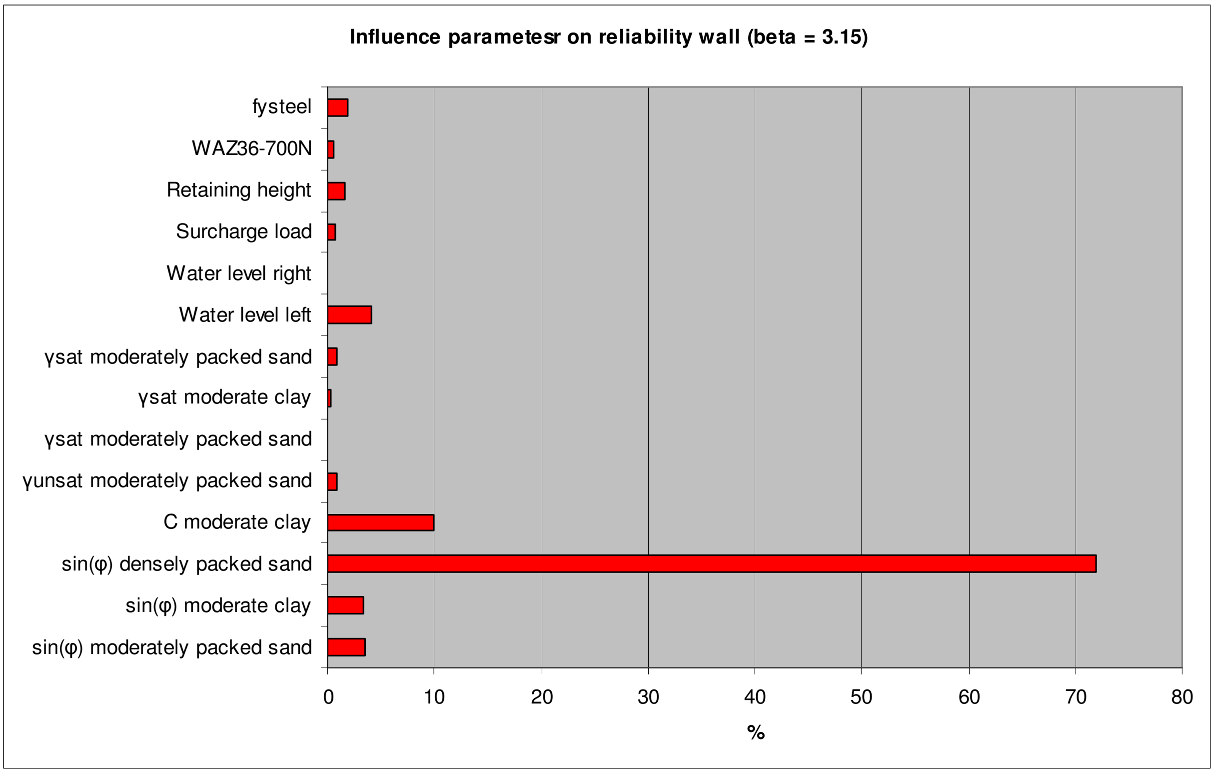

Figure G-2 Influence in % from parameters on reliability calculation Blum wall failure

It is clear that the additional parameters retaining height, water levels and surcharge hardly influence the reliability of the structure with respect to wall failure in bending. This shows that it is no problem that these parameters cannot be included in the PLAXIS calculations for LS wall failure in bending.

G.1.3 Results soil mechanical failure

The obtained reliability index for soil mechanical failure is β = 1.78. The influence factors are given in Table G-3 and visualised in percentages in Figure G-3.

Parameter	**α**
$\varphi_{moderate\ clay}$	0.15
$\varphi_{moderately\ packed\ sand}$	0.15
$\varphi_{densely\ packed\ sand}$	0.89
$C_{moderate\ clay}$	0.30
$\gamma_{sat,moderate\ clay}$	0.00
$\gamma_{sat,moderately\ packed\ sand}$	0.00
$\gamma_{sat,densely\ packed\ sand}$	0.10
$\gamma_{unsat,moderately\ packed\ sand}$	0.06
Water level (outside)	0.15
Water level (right)	0.00
Surcharge load	0.08
Retaining height	0.15
Length sheet-pile	0.09

Table G-3 Influence factors soil mechanical failure with Blum

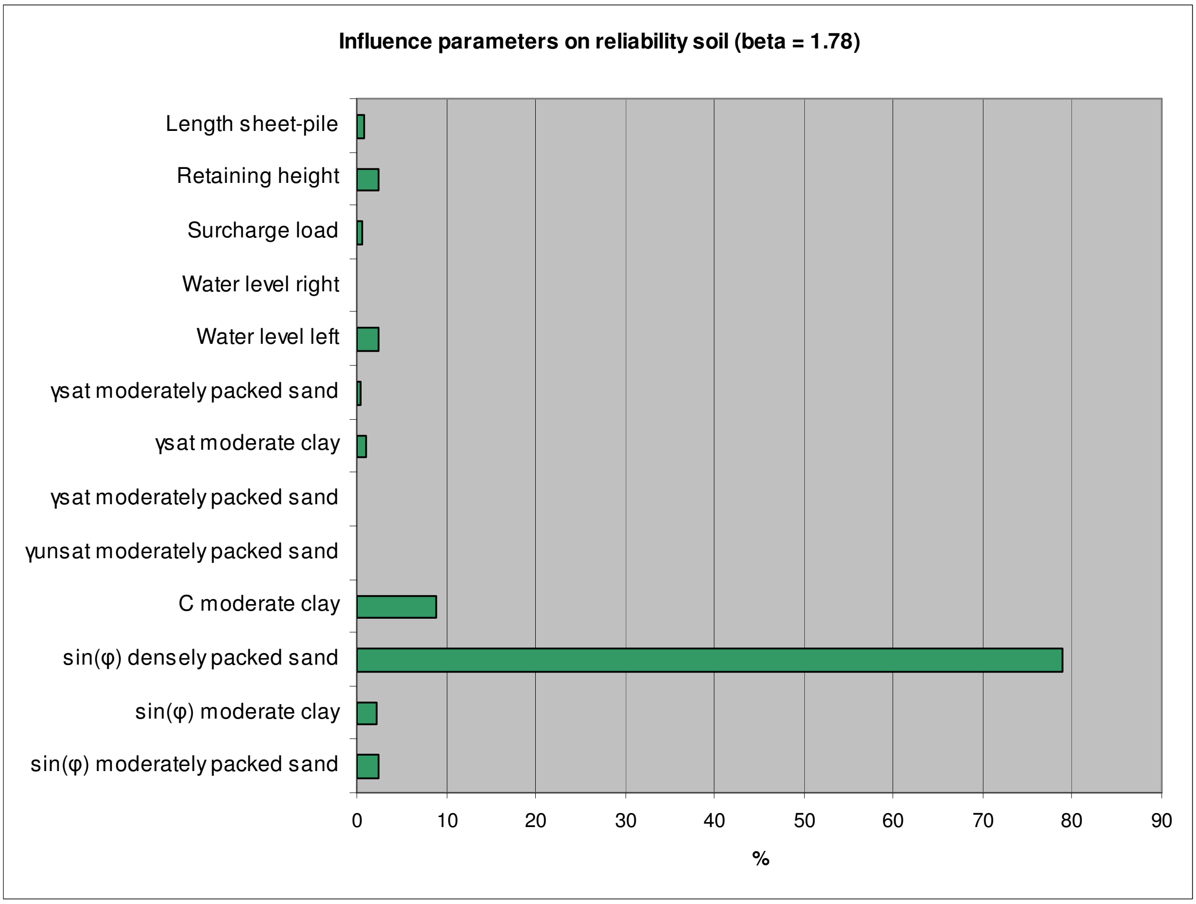

Figure G-3 Influence in % from parameters on reliability calculation Blum soil mechanical failure

The reliability index with respect to soil mechanical failure is low according to the Blum probabilistic calculation (it should be 4.396 (CUR 211, 2003). This implies that the sheet-pile is in fact too short. This is a problem that will affect the other results as well, because the PLAXIS calculations also work with a wall length of 21 m.

Like for the other failure mechanisms, also for soil mechanical failure the additional parameters hardly influence the reliability. It is no problem that they cannot be included in the PLAXIS calculations.

H. Appendix - Output first calculations anchored sheet-pile

This Appendix presents the calculation results of the first exploratory calculations for each failure mechanism for the first benchmark. Based on these calculations several parameters are eliminated from the final calculation.

H.1.1 Anchor failure (ULS)

The first calculation includes the C of the clay layer, sin(φ) of all layers, the anchor parameters and sheet-pile parameters. The output is shown in Table H-1.

Number of calculations (FORM): 101				
β: 4.339				
P_f: $7.167*10^{-6}$				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
D_a	0.032	0.03	0.0426	[m]
$f_{y,steel}$	0.07	0.40	351800	[kN/m²]
EA_a	0.07	0.28	13120	[kN/m]
$C_{moderate\ clay}$	0.8	0.19	5.71	[kPa]
$\sin(\varphi)_{moderate\ clay}$	0.18	0.27	0.48	[-]
$\sin(\varphi)_{moderately\ packed\ sand}$	0.18	0.56	0.46	[-]
$\sin(\varphi)_{densely\ packed\ sand}$	0.18	0.57	0.43	[-]
$d_{AZ36\text{-}700N}$	0.03	0.00	0.706	[kN/m]
$w_{AZ36\text{-}700N}$	0.04	0.00	1.81	[kN/m]
$G_{eq,AZ36\text{-}700N}$	0.07	0.00	2691759	[kN/m²/m]

calc.	Z-value	
1	311,70	
101	-31,12	

Table H-1 Output calculation 1 (LS Anchor)

The point that draws attention is the 0.00 influence factor for all sheet-pile parameters. It is clear that these parameters do not influence the reliability of the structure with respect to anchor failure. Figure H-1 gives an overview of the influence percentage (α^2*100) for each parameter. sin(φ) of the both sand layers are the most important parameters and also the anchor parameters are relevant.

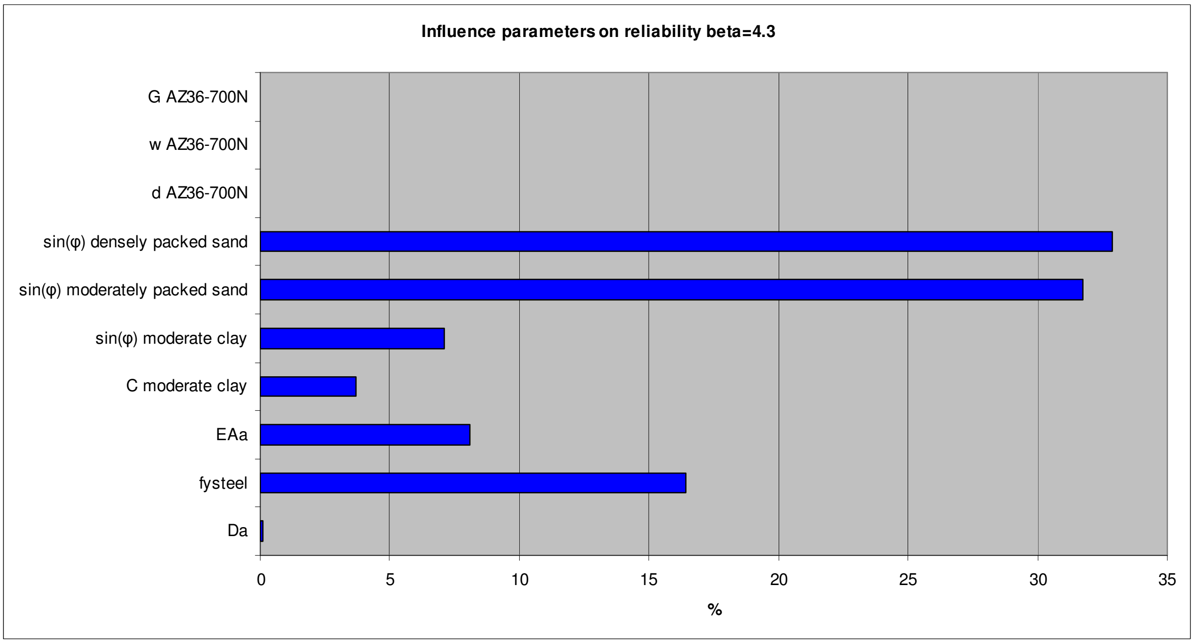

Figure H-1 Influence in % from parameters on reliability calculation 1 (LS Anchor)

The second calculation includes the C of the clay layer, sin(φ) of all layers and the three stiffness parameters for all soil layers. Furthermore the anchor parameters are included. The output is shown in Table H-2.

Number of calculations (FORM): 86				
β: 3.863				
P_f : $5.604*10^{-4}$				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
D_a	0.032	0.07	0.0428	[m]
$f_{y,steel}$	0.07	0.36	361700	[kN/m^2]
EA_a	0.07	0.26	13370	[kN/m]
$C_{moderate\ clay}$	0.8	0.08	8.64	[kPa]
$E_{50,moderate\ clay}$	0.3	0.00	6830	[kPa]
$E_{50,moderately\ packed\ sand}$	0.3	0.00	37900	[kPa]
$E_{50,densely\ packed\ sand}$	0.3	0.00	95870	[kPa]
$E_{oed,moderate\ clay}$	0.3	0.00	4645	[kPa]
$E_{oed,moderately\ packed\ sand}$	0.3	0.51	37900	[kPa]
$E_{oed,densely\ packed\ sand}$	0.3	0.00	95910	[kPa]
$G_{moderate\ clay}$	0.3	0.05	5692	[kPa]
$G_{moderately\ packed\ sand}$	0.3	0.00	47370	[kPa]
$G_{densely\ packed\ sand}$	0.3	0.21	119900	[kPa]
$\sin(\varphi)_{moderate\ clay}$	0.18	0.17	0.45	[-]
$\sin(\varphi)_{moderately\ packed\ sand}$	0.18	0.61	0.35	[-]
$\sin(\varphi)_{densely\ packed\ sand}$	0.18	0.29	0.52	[-]

calc.	Z-value
1	311.90
86	5.51

Table H-2 Output calculation 2 (LS Anchor)

From the stiffness parameters only G of the densely packed sand layer and the E_{oed} of the moderately packed sand layer are relevant (Figure H-1). The others can be eliminated from the final probabilistic calculation.

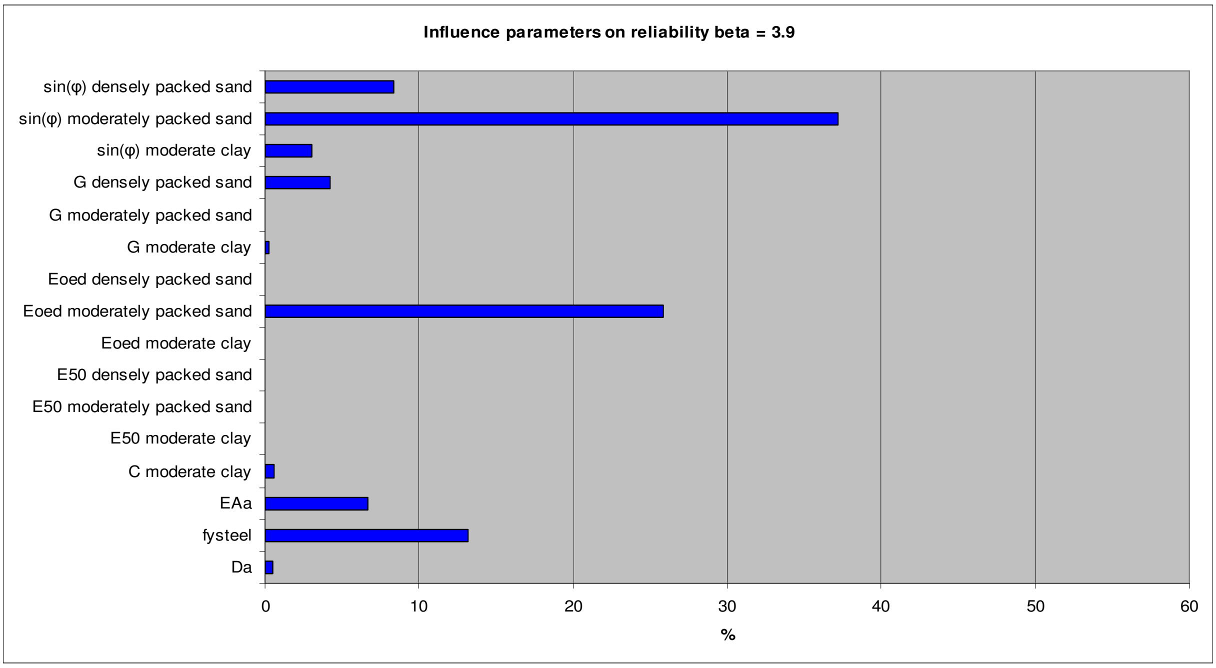

Figure H-2 Influence in % from parameters on reliability calculation 2 (LS Anchor)

The third calculation includes the sin(φ) and sin(ψ) of the sand layers, m, R_{int} and γ_{sat} of all layers, γ_{unsat} of the moderately packed sand layer and the anchor parameters. The output is shown in Table H-3.

Number of calculations (FORM): 163				
β: 3.886				
P_f: 5.101*10^{-5}				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
D_a	0.09	0.09	0.0427	[m]
$f_{y,steel}$	0.07	0.38	359800	[kN/m^2]
EA_a	0.07	0.28	13300	[kN/m]
$m_{moderate\ clay}$	0.2	0.04	0.98	[-]
$m_{moderately\ packed\ sand}$	0.2	0.02	0.50	[-]
$m_{densely\ packed\ sand}$	0.2	0.15	0.49	[-]
$R_{int,moderate\ clay}$	0.2	0.07	0.60	[-]
$R_{int,moderately\ packed\ sand}$	0.2	0.11	0.80	[-]
$R_{int,densely\ packed\ sand}$	0.2	0.01	0.86	[-]
$\sin(\varphi)_{moderately\ packed\ sand}$	0.18	0.60	0.36	[-]
$\sin(\varphi)_{densely\ packed\ sand}$	0.18	0.40	0.49	[-]
$\sin(\psi)_{moderately\ packed\ sand}$	0.18	0.01	0.05	[-]
$\sin(\psi)_{densely\ packed\ sand}$	0.18	0.00	0.10	[-]
$\gamma_{sat,moderate\ clay}$	0.05	0.05	17.32	[kN/m^3]
$\gamma_{sat,moderately\ packed\ sand}$	0.05	0.00	20.52	[kN/m^3]
$\gamma_{sat,densely\ packed\ sand}$	0.05	-0.17	21.21	[kN/m^3]
$\gamma_{unsat,moderately\ packed\ sand}$	0.05	0.42	18.36	[kN/m^3]
calc.	Z-value			
1	185.40			
163	2.41			

Table H-3 Output calculation 3 (LS Anchor)

The table shows that the sin(ψ) parameters hardly influence the reliability. The R_{int} and m parameters are also not really important and can be eliminated. From the specific soil weight only the γ_{unsat} of the moderately packed sand layer is included. It is important to note that the γ_{sat} of the densely packed sand layer has a negative α-value. This implies that this parameter influences the reliability in the opposite positive way, i.e. when the saturated soil weight is reduced the reliability index increases. Basically the parameter is a 'load parameter' in stead of 'resistance parameter'. However its influence is limited. The results are visualised in Figure H-3.

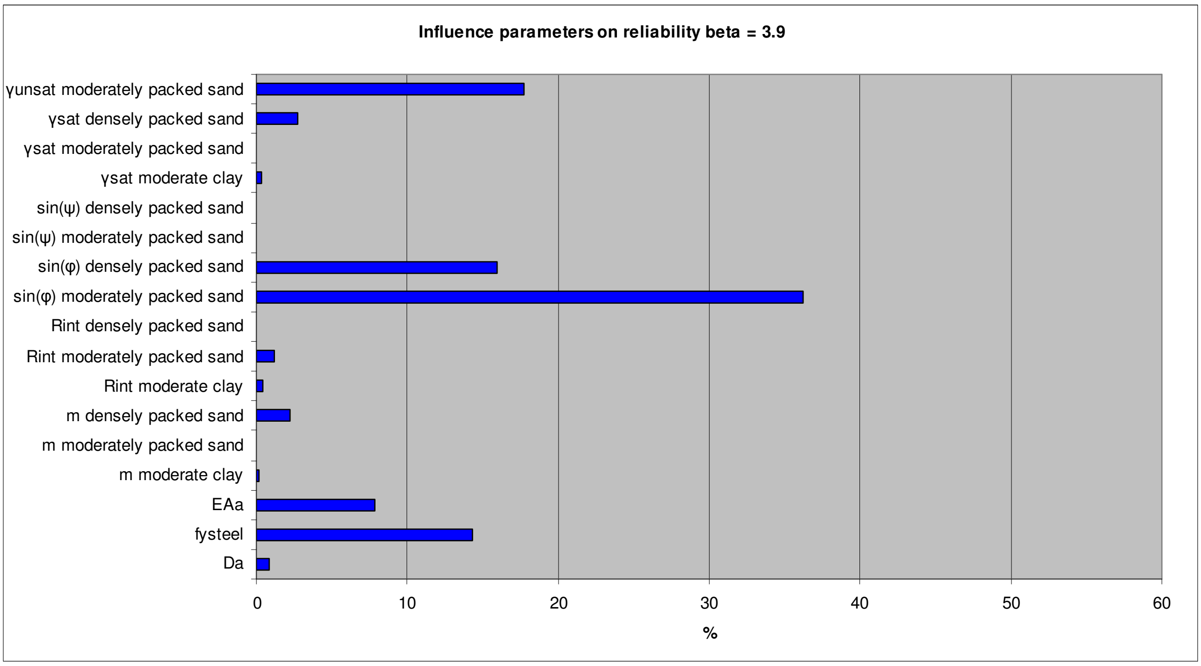

Figure H-3 Influence in % from parameters on reliability calculation 3 (LS Anchor)

H.1.2 Wall failure in bending (ULS)

The first calculation includes the C of the clay layer, sin(φ) of all layers, the anchor parameters and sheet-pile parameters. The output is shown in Table H-4.

Number of calculations (FORM): 265				
β: 4.558				
P_f: 2.579*10^{-6}				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
EA_a	-0.07	14030	12340	[kN/m]
$C_{moderate\ clay}$	0.18	5.67	5.67	[kPa]
$\sin(\varphi)_{moderate\ clay}$	0.25	0.47	0.49	[-]
$\sin(\varphi)_{moderately\ packed\ sand}$	0.25	0.55	0.47	[-]
$\sin(\varphi)_{densely\ packed\ sand}$	0.90	0.27	0.53	[-]
$d_{AZ36\text{-}700N}$	-0.01	0.70	0.70	[kN/m]
$w_{AZ36\text{-}700N}$	0.09	1.81	1.81	[kN/m]
$G_{eq,AZ36\text{-}700N}$	0.00	2718000	2718000	[kN/m^2/m]
$W_{AZ36\text{-}700N}$	0.06	0,003769	0.003769	[m^3/m]
$f_{y,steel}$	0.19	376300	376300	[kN/m^2]

calc.	Z-value
1	917.80
265	-1.00[1]

Table H-4 Output calculation 1 (LS Wall)

It is clear that the anchor parameter does not influence the reliability with respect to wall failure. Furthermore, the shear modulus (G), weight (w) and equivalent thickness (d) of the sheet-pile are not very relevant and can eventually be eliminated from the probabilistic calculation. The sin(φ) of the densely packed sand layer is the most important parameter. This is also visualised in Figure H-4.

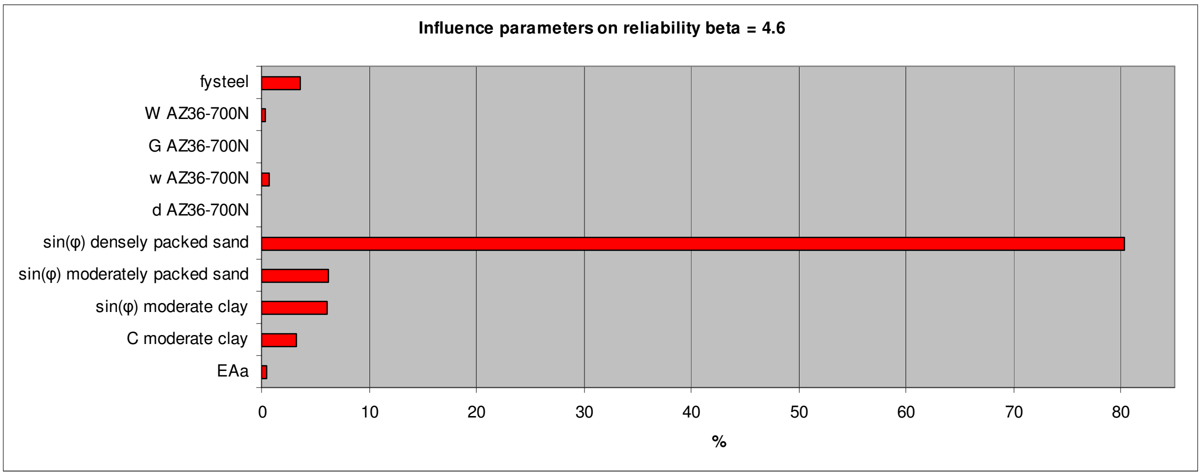

Figure H-4 Influence in % from parameters on reliability calculation 1 (LS Wall)

The second calculation includes the C of the clay layer, sin(φ) of all layers, the three stiffness parameters for all soil layers and the sheet-pile parameters (W_{el} and $f_{y,s}$). The output is shown in Table H-5.

[1] The final Z-value is -1.00. This implies that at the reached design point the structure just failed due to soil mechanical failure (Option Evaluation Switch in Prob2B). It is manually checked that this is indeed 'just soil mechanical failure'. The wall was also about to fail due to the large bending moments. Therefore the calculation is correct.

Number of calculations (FORM): 171				
β: 4.163				
P_f: $1.570*10^{-5}$				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
$C_{\text{moderate clay}}$	0.8	0.16	6.75	[kPa]
$E_{50,\text{moderate clay}}$	0.3	0.00	6264	[kPa]
$E_{50,\text{moderately packed sand}}$	0.3	0.00	43360	[kPa]
$E_{50,\text{densely packed sand}}$	0.3	0.00	83160	[kPa]
$E_{oed,\text{moderate clay}}$	0.3	0.00	4259	[kPa]
$E_{oed,\text{moderately packed sand}}$	0.3	0.36	43360	[kPa]
$E_{oed,\text{densely packed sand}}$	0.3	0.00	83160	[kPa]
$G_{\text{moderate clay}}$	0.3	0.10	5220	[kPa]
$G_{\text{moderately packed sand}}$	0.3	0.00	54200	[kPa]
$G_{\text{densely packed sand}}$	0.3	0.42	104000	[kPa]
$\sin(\varphi)_{\text{moderate clay}}$	0.18	0.20	0.46	[-]
$\sin(\varphi)_{\text{moderately packed sand}}$	0.18	0.40	0.43	[-]
$\sin(\varphi)_{\text{densely packed sand}}$	0.18	0.66	0.31	[-]
$W_{AZ36-700N}$	0.04	0.06	0.003822	[m^3/m]
$f_{y,steel}$	0.07	0.15	387300	[kN/m^2]

	Z-value	
1	731.00	
171	-20.39	

Table H-5 Output calculation 2 (LS Wall)

From the stiffness parameters only G of the densely packed sand layer and E_{oed} of the moderately packed sand layer are relevant in the probabilistic calculation (Figure H-5). The others can be eliminated from the final probabilistic calculation.

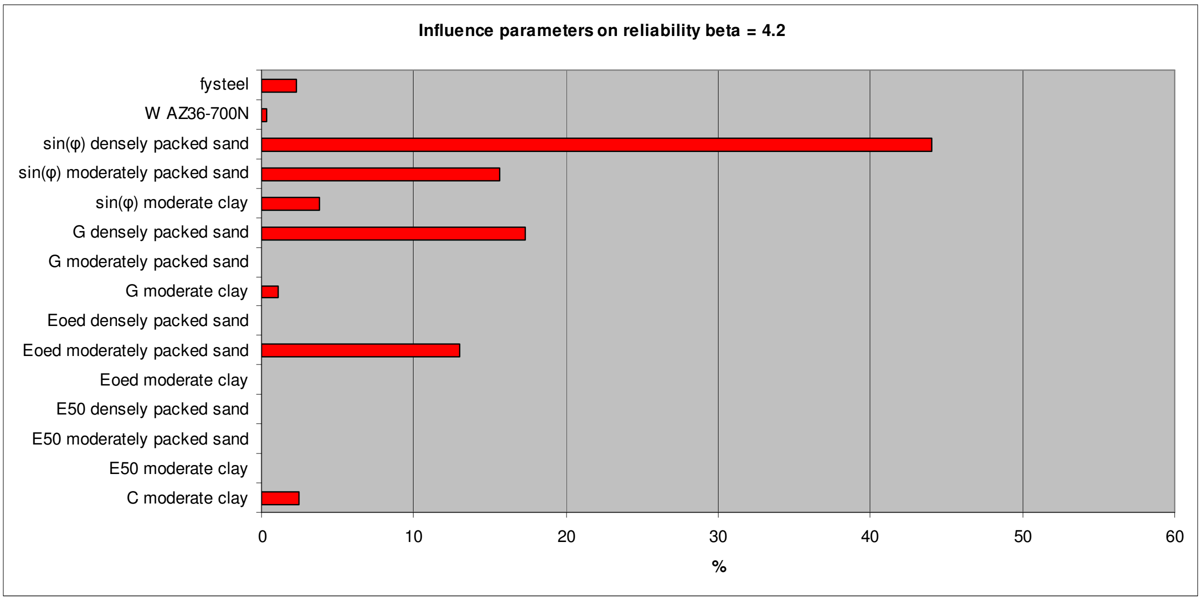

Figure H-5 Influence in % from parameters on reliability calculation 2 (LS Wall)

The third calculation includes the sin(φ) and sin(ψ) of all sand layers, m, R_{int}, γ_{sat} of all layers, γ_{unsat} of the moderately packed sand layer and the sheet-pile parameters (W_{el} and $f_{y,s}$). The output is shown in Table H-6.

Number of calculations (FORM): 199				
β: 4.513				
P_f: $3.202*10^{-6}$				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
$m_{moderate\ clay}$	0.2	-0.07	1.04	[-]
$m_{moderately\ packed\ sand}$	0.2	0.00	0.49	[-]
$m_{densely\ packed\ sand}$	0.2	0.06	0.49	[-]
$R_{int,moderate\ clay}$	0.2	0.06	0.62	[-]
$R_{int,moderately\ packed\ sand}$	0.2	-0.05	0.89	[-]
$R_{int,densely\ packed\ sand}$	0.2	0.03	0.84	[-]
$\sin(\varphi)_{moderately\ packed\ sand}$	0.18	0.48	0.39	[-]
$\sin(\varphi)_{densely\ packed\ sand}$	0.18	0.67	0.29	[-]
$\sin(\psi)_{moderately\ packed\ sand}$	0.18	0.01	0.05	[-]
$\sin(\psi)_{densely\ packed\ sand}$	0.18	0.05	0.10	[-]
$\gamma_{sat,moderate\ clay}$	0.05	0.06	17.27	[kN/m^3]
$\gamma_{sat,moderately\ packed\ sand}$	0.05	0.00	20.61	[kN/m^3]
$\gamma_{sat,densely\ packed\ sand}$	0.05	-0.44	21.05	[kN/m^3]
$\gamma_{unsat,moderately\ packed\ sand}$	0.05	0.30	18.44	[kN/m^3]
$W_{AZ36\text{-}700N}$	0.03	0.06	0.003819	[m^3/m]
$f_{y,steel}$	0.04	0.13	388700	[kN/m^2]

calc.	Z-value	
1	720,00	
199	-1,00[2]	

Table H-6 Output calculation 3 (LS Wall)

The table shows that the power parameters as well as the sin(ψ) parameters hardly influence the reliability The R_{int} parameters are also not important and can be eliminated. From the specific soil weight only the γ_{unsat} of the moderately packed sand layer and the γ_{sat} of the densely packed sand layer are included. It is important to note that the γ_{sat} of the densely packed sand layer has a negative α-value. This implies that this parameter influences the reliability in a positive way, i.e. when the saturated soil weight is reduced the reliability index increases. The results are visualised in Figure H-6.

[2] The final Z-value is -1.00. This implies that at the reached design point the structure just failed due to soil mechanical failure (Option Evaluation Switch in Prob2B). It is manually checked that this is indeed ‘just soil mechanical failure’. The wall was also about to fail due to the large bending moments.

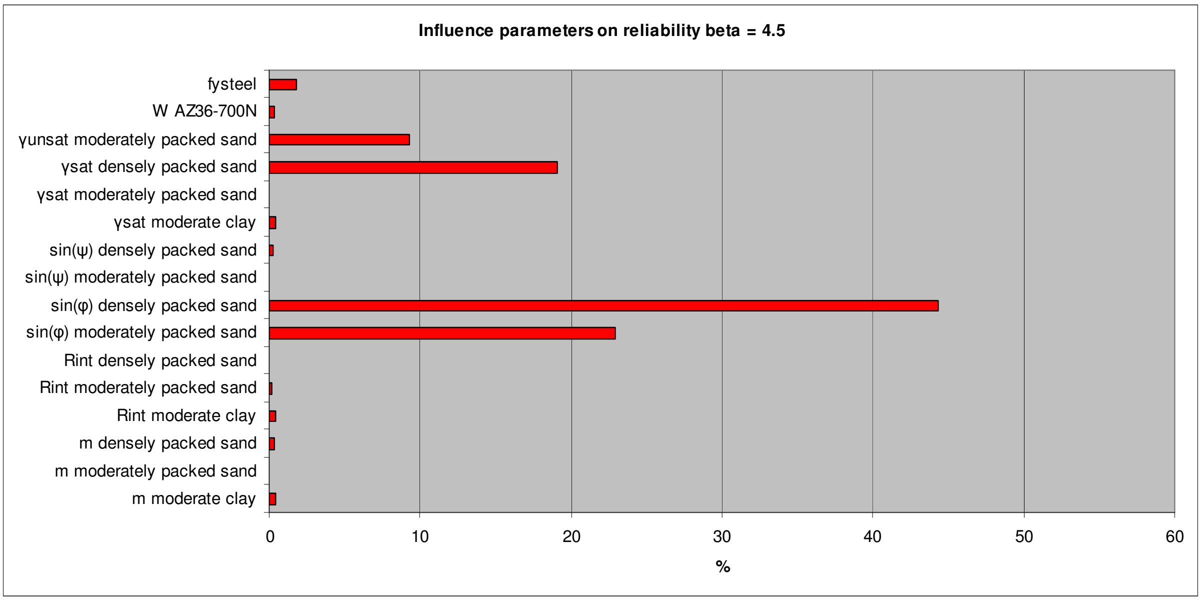

Figure H-6 Influence in % from parameters on reliability calculation 3 (LS Wall)

H.1.3 Soil mechanical failure (ULS)

The first calculation includes the C of the clay layer and sin(φ) of all layers. The output is shown in Table H-7, including the value of MSF at which the design point was found.

Number of calculations (FORM): 46				
β: 3.058				
P_f: 1.116*10^{-3}				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
$C_{\text{moderate clay}}$	0,8	0.19	7.70	[kPa]
$\sin(\varphi)_{\text{moderate clay}}$	0,18	0.19	0.41	[-]
$\sin(\varphi)_{\text{moderately packed sand}}$	0,18	0.15	0.58	[-]
$\sin(\varphi)_{\text{densely packed sand}}$	0.18	0.95	0.32	[-]

calc.	Z-value	
1	1.28	
46	0.03	**MSF = 1.13**

Table H-7 Output calculation 1 (LS Soil)

sin(φ) appeared to be by far the most important parameter (Figure H-7).

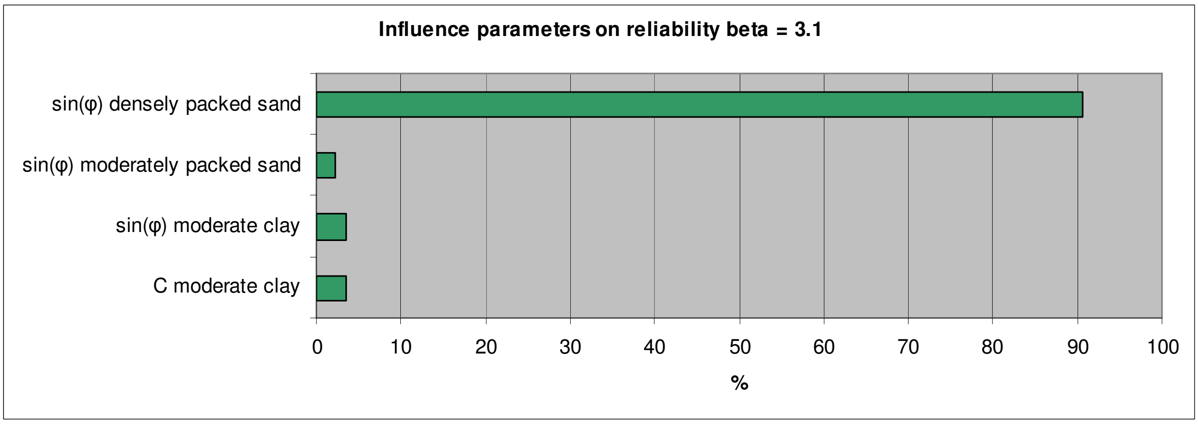

Figure H-7 Influence in % from parameters on reliability calculation 1 (LS Soil)

The second calculation includes sin(φ), the anchor parameter and sheet-pile parameters. The output is shown in Table H-8.

Number of calculations (FORM): 25				
β: 3.264				
P_f: $5.486*10^{-4}$				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
EA_a	0.07	0.02	14210	[kN/m]
$\sin(\varphi)_{densely\ packed\ sand}$	0.18	1.00	0.28	[-]
$d_{AZ36\text{-}700N}$	0.03	0.00	0.71	[kN/m]
$w_{AZ36\text{-}700N}$	0.04	0.00	1.81	[kN/m]
$G_{eq,AZ36\text{-}700N}$	0.07	0.00	2692000	[kN/m^2/m]
calc.	Z-value			
1	0.04			
25	0.00			**MSF = 1.10**

Table H-8 Output calculation 2 (LS Soil)

The sheet-pile parameters and anchor parameter have no influence on the reliability (Figure H-8).

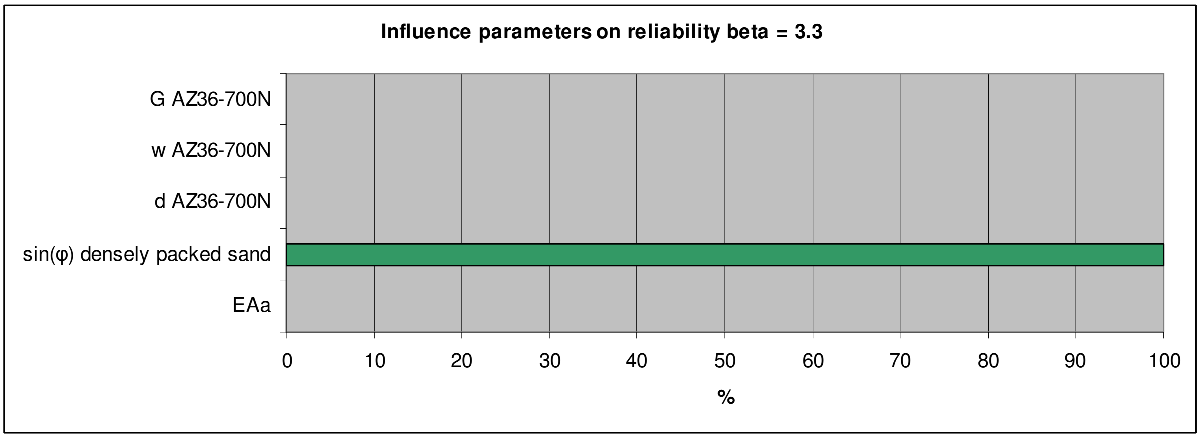

Figure H-8 Influence in % from parameters on reliability calculation 2 (LS Soil)

The third calculation includes the sin(φ) of the densely packed sand and all stiffness parameters of all soil layers. The output is shown in Table H-3.

Number of calculations (FORM): 56				
β: 3.792				
P_f: $7.467*10^{-5}$				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
$E_{50,moderate\ clay}$	0.3	-0.16	7949	[kPa]
$E_{50,moderately\ packed\ sand}$	0.3	0.05	62070	[kPa]
$E_{50,densely\ packed\ sand}$	0.3	0.00	84720	[kPa]
$E_{oed,moderate\ clay}$	0.3	0.00	5963	[kPa]
$E_{oed,moderately\ packed\ sand}$	0.3	-0.14	62070	[kPa]
$E_{oed,densely\ packed\ sand}$	0.3	0.00	84720	[kPa]
$G_{moderate\ clay}$	0.3	0.00	7308	[kPa]
$G_{moderately\ packed\ sand}$	0.3	-0.01	77580	[kPa]
$G_{densely\ packed\ sand}$	0.3	0.35	105900	[kPa]

$\sin(\varphi)_{densely\ packed\ sand}$	0.18	0.91	0.30	[-]

calc.	Z-value	
1	0.45	
56	0.07	**MSF = 1.17**

Table H-9 Output calculation 3 (LS Soil)

Again sin(φ) of the lower sand layer is by far the most important parameter in the probabilistic calculation. G of this layer also has significant influence. E_{oed} of the moderately packed sand and E_{50} of the clay layer both have small 'opposite' influence on the reliability (α<0). The other stiffness parameters can be eliminated from the final calculation. The influence of the parameters is visualised in Figure H-9.

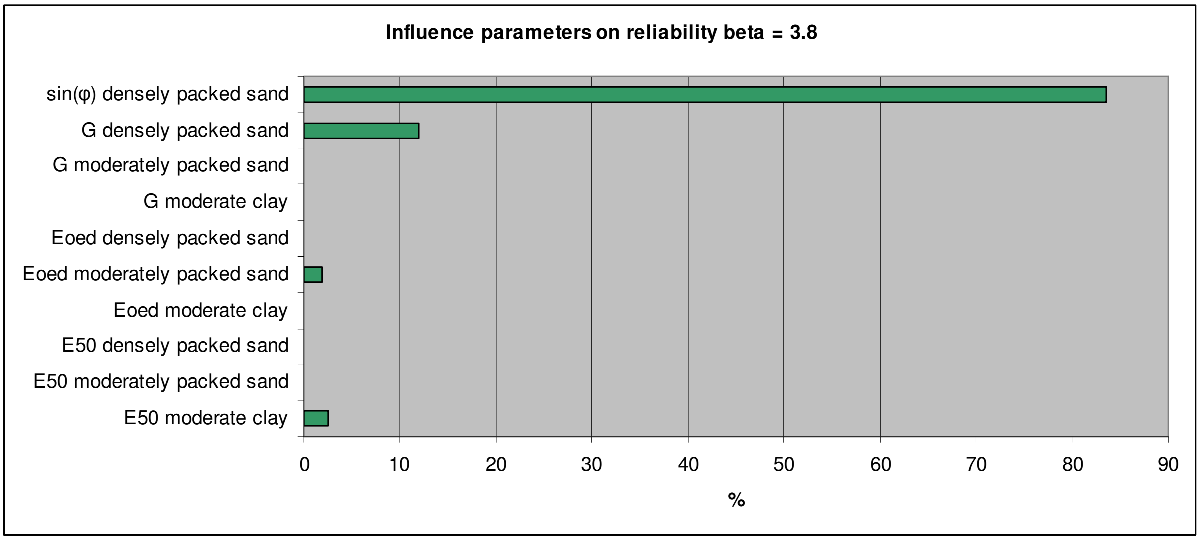

Figure H-9 Influence in % from parameters on reliability calculation 3 (LS Soil)

The fourth calculation includes sin(φ) of the densely packed sand, sin(ψ) of both sand layers and the relevant specific (un)saturated soil weight (γ) of all soil layers. The output is shown in Table H-10.

Number of calculations (FORM): 25				
β: 3.038				
P_f: $1.192 \cdot 10^{-3}$				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
$\sin(\varphi)_{densely\ packed\ sand}$	0.18	0.39	0.31	[-]
$\sin(\psi)_{moderately\ packed\ sand}$	0.18	-0.05	0.05	[-]
$\sin(\psi)_{densely\ packed\ sand}$	0.18	-0.01	0.10	[-]
$\gamma_{sat, moderate\ clay}$	0.05	-0.02	17.49	[kN/m^3]
$\gamma_{sat,moderately\ packed\ sand}$	0.05	-0.12	21.33	[kN/m^3]
$\gamma_{sat,densely\ packed\ sand}$	0.05	0.89	19.78	[kN/m^3]
$\gamma_{unsat,moderately\ packed\ sand}$	0.05	-0.20	19.08	[kN/m^3]

calc.	Z-value	
1	0.14	
25	0.05	**MSF = 1.15**

Table H-10 Output calculation 4 (LS Soil)

γ_{sat} of the densely packed sand layer is the most important parameter. sin(φ) of this layer is also important. The other parameters influence the reliability positively. γ_{unsat} is also relevant for the final calculation, while the others can be eliminated. The results are visualised in Figure H-10. From this figure it can also be concluded that the parameters of the earlier calculations that were relatively important with respect to sin(φ), can be eliminated. This can be done because sin(φ) has a much smaller influence on the reliability than γ_{sat} of the densely packed sand layer. sin(φ), C and E_{50} of the clay layer, sin(φ) of the moderately packed sand layer and G of the densely packed sand layer can be eliminated as they are not important in comparison to γ_{sat} of the densely packed sand layer.

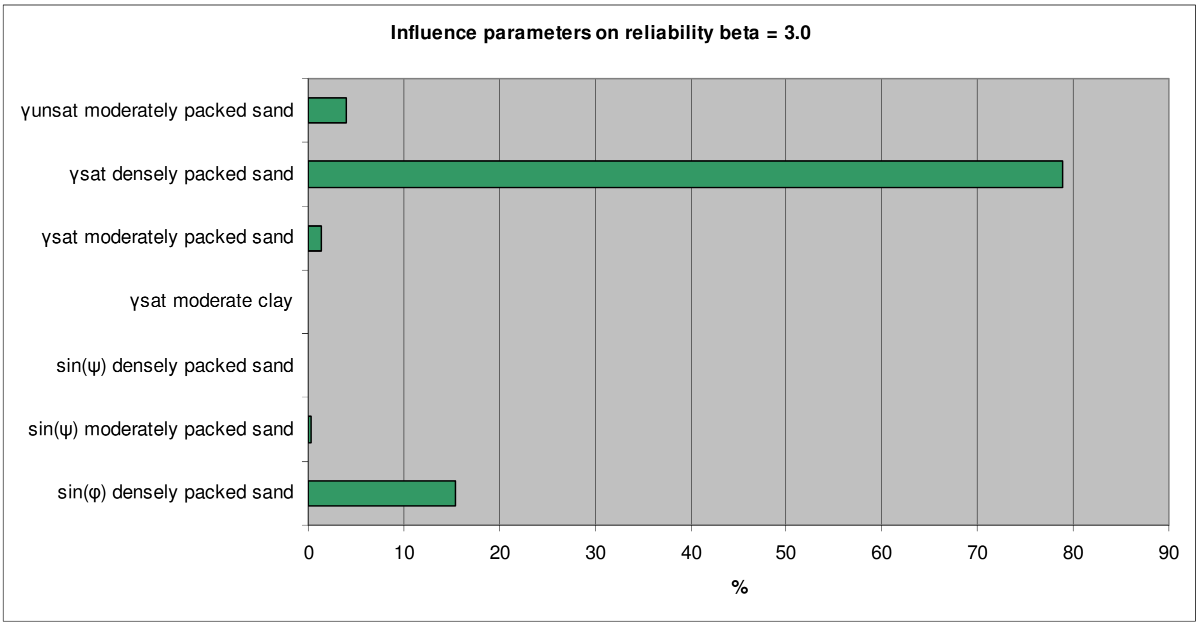

Figure H-10 Influence in % from parameters on reliability calculation 4 (LS Soil)

The fifth calculation includes the two most important parameters of the previous calculation (γ_{sat} and sin(φ) of the densely packed sand layer) and power m and interface condition R_{int} of all soil layers. The output is presented in Table H-11.

Number of calculations (FORM): 46				
β: 3.098				
P_f: $9.726*10^{-4}$				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
$m_{moderate\ clay}$	0.2	0.10	0.94	[-]
$m_{moderately\ packed\ sand}$	0.2	-0.03	0.51	[-]
$m_{densely\ packed\ sand}$	0.2	0,03	0.49	[-]
$R_{int,moderate\ clay}$	0.2	0.06	0.65	[-]
$R_{int,moderately\ packed\ sand}$	0.2	0.00	0.90	[-]
$R_{int,densely\ packed\ sand}$	0.2	0.11	0.84	[-]
$\sin(\varphi)_{densely\ packed\ sand}$	0.18	0.41	0.30	[-]
$\gamma_{sat,densely\ packed\ sand}$	0.05	0.90	19.75	[kN/m^3]

calc.	Z-value	
1	0.09	
46	0.02	**MSF = 1.12**

Table H-11 Output calculation 5 (LS Soil)

From the fifth calculation no additional parameters appeared to be important, as shown in Figure H-11.

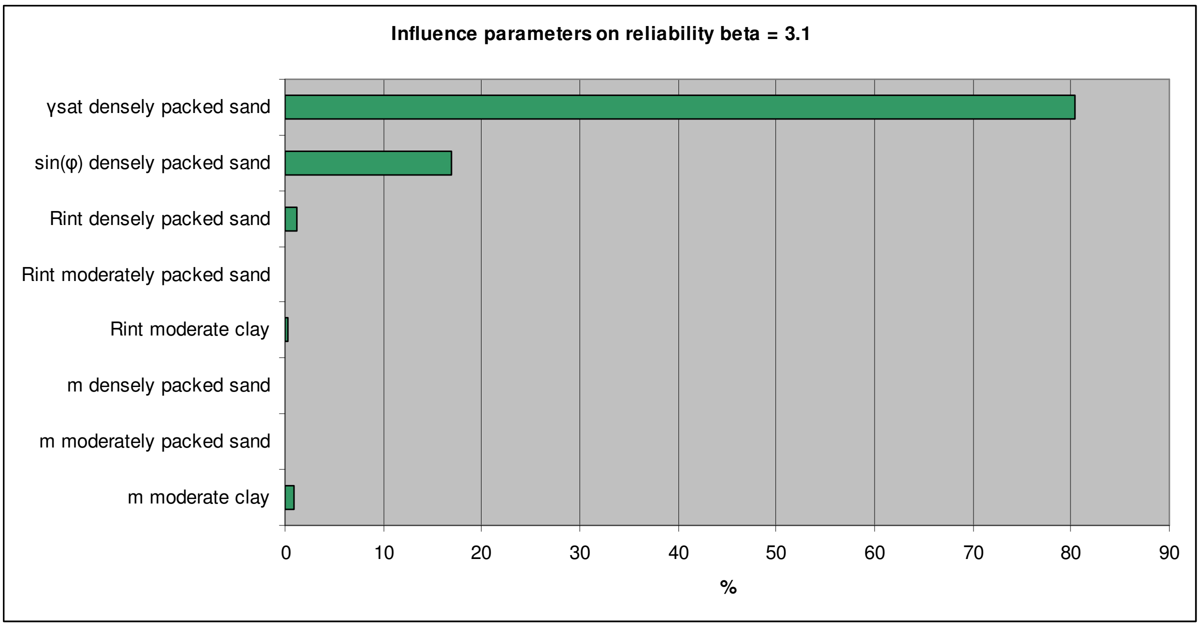

Figure H-11 Influence in % from parameters on reliability calculation 5 (LS Soil)

H.1.4 Excessive deformations (SLS)

The output of the calculation with all stochastic parameters is shown in Table H-12. The influence of the different parameters is shown in Figure H-12.

Number of calculations (FORM): 931				
β: 2.430				
P_f: 7.541*10^{-3}				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
EA_a	0.07	0.01	14180	[kN/m]
$C_{moderate\ clay}$	0.8	0.11	7.90	[kPa]
$E_{50,moderate\ clay}$	0.3	0.00	6628	[kPa]
$E_{50,moderately\ packed\ sand}$	0.3	0.00	64700	[kPa]
$E_{50,densely\ packed\ sand}$	0.3	0.00	88970	[kPa]
$E_{oed,moderate\ clay}$	0.3	0.00	4507	[kPa]
$E_{oed,moderately\ packed\ sand}$	0.3	0.06	64700	[kPa]
$E_{oed,densely\ packed\ sand}$	0.3	0.00	88970	[kPa]
$G_{moderate\ clay}$	0.3	0.17	5523	[kPa]
$G_{moderately\ packed\ sand}$	0.3	0.00	80870	[kPa]
$G_{densely\ packed\ sand}$	0.3	0.48	111200	[kPa]
$m_{moderate\ clay}$	0.2	-0.03	1.01	[-]
$m_{moderately\ packed\ sand}$	0.2	0.00	0.50	[-]
$m_{densely\ packed\ sand}$	0.2	0.06	0.51	[-]
$R_{int,moderate\ clay}$	0.2	0.07	0.64	[-]
$R_{int,moderately\ packed\ sand}$	0.2	-0.02	0.89	[-]
$R_{int,densely\ packed\ sand}$	0.2	0.04	0.87	[-]
$\sin(\varphi)_{moderate\ clay}$	0.18	0.13	0.44	[-]
$\sin(\varphi)_{moderately\ packed\ sand}$	0.18	0.18	0.58	[-]
$\sin(\varphi)_{densely\ packed\ sand}$	0.18	0.70	0.40	[-]
$\sin(\psi)_{moderately\ packed\ sand}$	0.18	0.04	0.05	[-]

$\sin(\psi)_{densely\ packed\ sand}$	0.18	0.05	0.10	[-]
$\gamma_{sat,moderate\ clay}$	0.05	0.25	16.98	[kN/m^3]
$\gamma_{sat,moderately\ packed\ sand}$	0.05	0.00	20.63	[kN/m^3]
$\gamma_{sat,densely\ packed\ sand}$	0.05	-0.31	20.29	[kN/m^3]
$\gamma_{unsat,moderately\ packed\ sand}$	0.05	0,06	18.46	[kN/m^3]
$d_{AZ36-700N}$	0.03	0,00	0.71	[kN/m]
$w_{AZ36-700N}$	0.04	0.00	1.81	[kN/m]
$G_{eq,AZ36-700N}$	0.07	0.00	2692000	[kN/m^2/m]

calc.	Z-value
1	0.07
931	0.00

Table H-12 Output calculation 1 (LS Deformation)

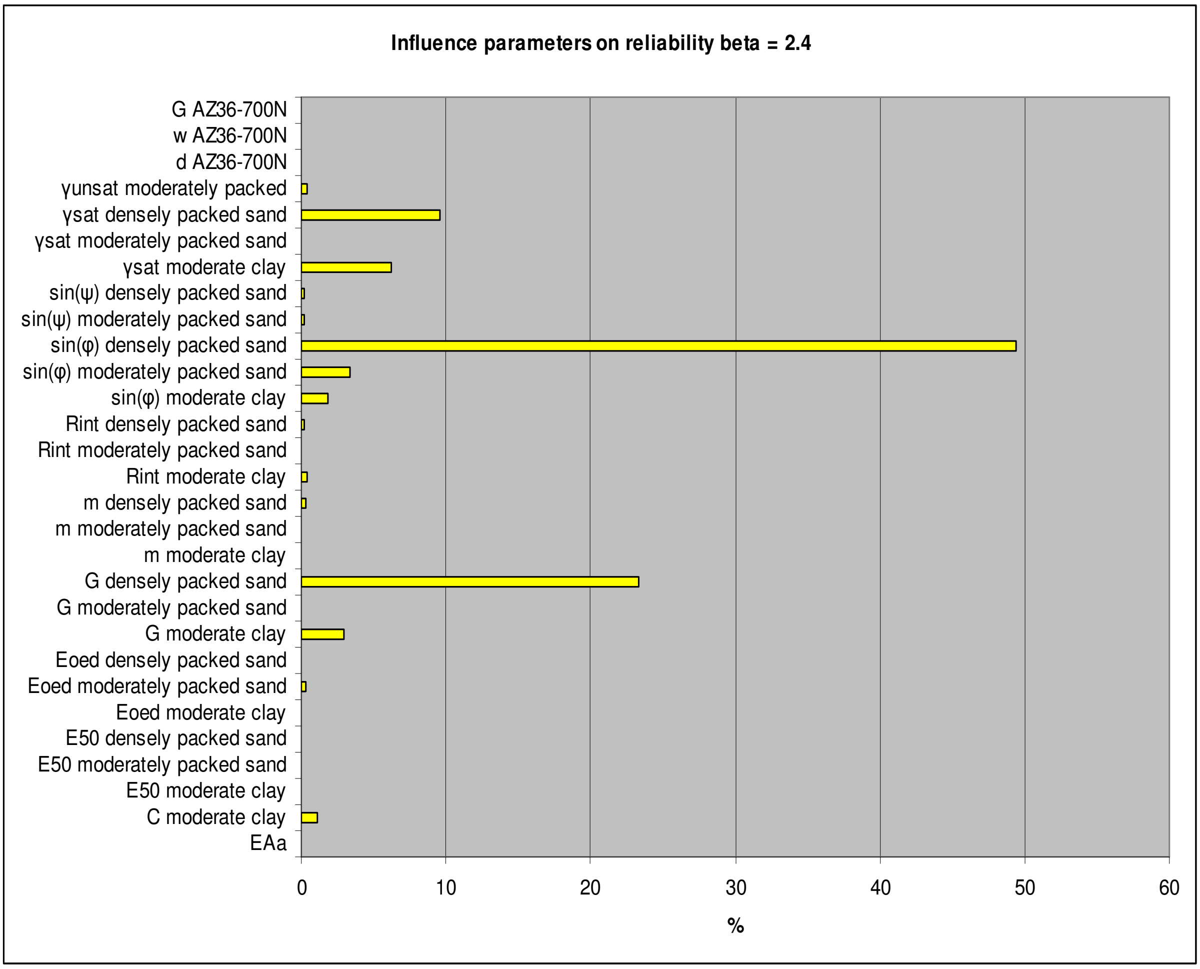

Figure H-12 Influence in % from parameters on reliability calculation 1 (LS deformation)

I. Appendix - Manual variation additional parameters anchored sheet-pile

This Appendix presents the results of the manual variation and inclusion of the geometrical and load parameters in the probabilistic analysis and the derivation of their partial safety factor. This is done for each failure mechanism for the benchmark 1 sheet-pile.

I.1.1 Anchor failure (ULS)

In the design point the three other parameters are varied manually in order to define α factors for the variations of these parameters in the governing situation as well. The results of the manual variation calculations are given in Table I-1.

Variation	$F_{anch,stage3}$ **[kN]**
No variation (design point)	518
Retaining height +0.35 m	540
Water level inside +0.05 m outside -0.25 m	536
Surcharge load +3 kN/m^2	537

Table I-1 Additional manual variations LS anchor

The α factors are all manually recalculated by using the FORM iteration before the final calculation. By using the FORM formula's the factors are calculated including the factors for the additional parameters. As the used data is not from the 'final' design point, but one step before, the influence factors slightly differ from the final output of Prob2B as visualised in Figure I-1. However for the sake of convenience the original influence factors are used combined with the manual found influence factors for the variations in the geometrical parameters and surcharge load. This implies that the sum of the α_i^2 is not necessarily 1, but it is still close to 1 as the influence of the additional parameters appears to be small.

The used α_i are given in Table I-2. The α factors are used to define partial safety factors for all parameters as presented in the main report. β is actually an overestimation of the situation, because the retaining height, water levels and surcharge load also influence this index. This difference in β cannot be quantified, because the design point does not change with respect to the original design point.

X_i	α_i
D_a	0.06
$f_{y,steel}$	0.31
EA_a	0.37
$E_{oed,moderately\ packed\ sand}$	0.20
$G_{densely\ packed\ sand}$	0.23
$\sin(\varphi)_{moderately\ packed\ sand}$	0.58
$\sin(\varphi)_{densely\ packed\ sand}$	0.19
$\gamma_{unsat,moderately\ packed\ sand}$	0.54
Retaining height	0.12
Water level	0.10
Surcharge load	0.11

Table I-2 α factors including additional parameters

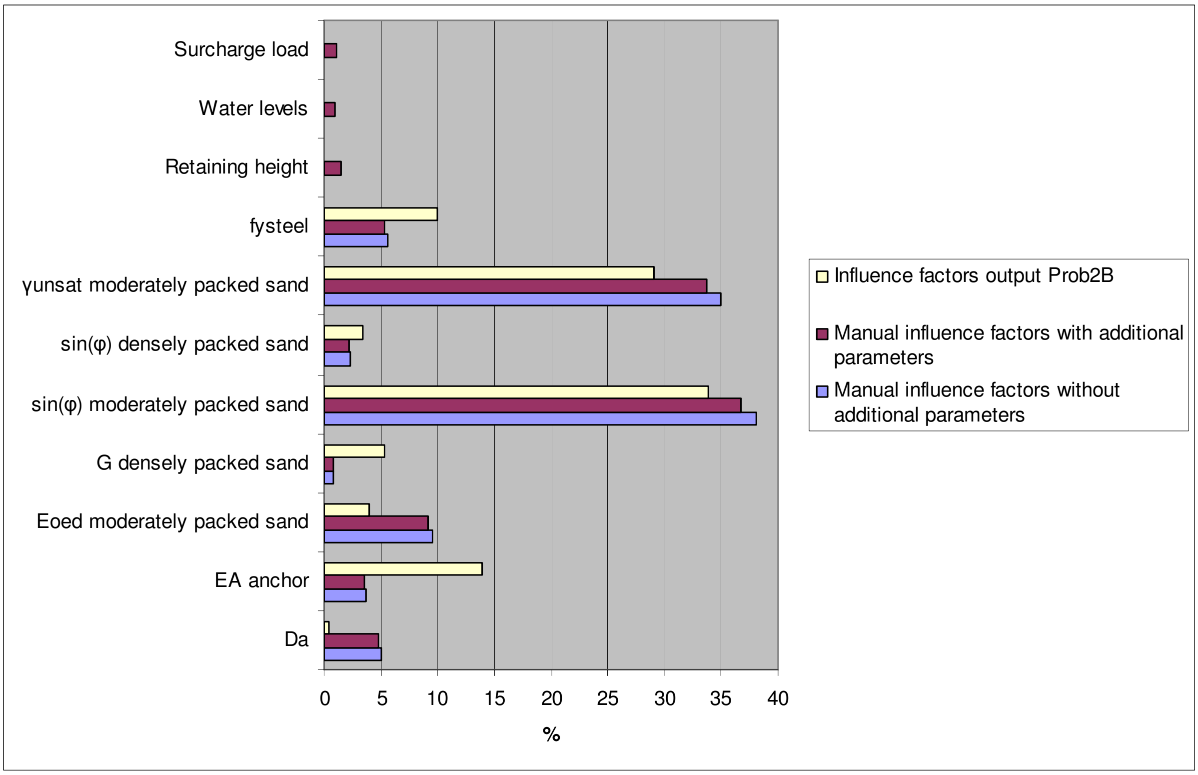

Figure I-1 Influence parameters on reliability beta = 3.60

I.1.2 Wall failure in bending (ULS)

In the design point the three other parameters are varied manually in order to define α factors for the variations of these parameters in the governing situation as well. The results of the manual variation calculations are given in Table I-3.

Variation	$M_{wall,stage3}$ **[kNm]**
No variation (design point)	1280
Retaining height +0.35 m	1357
Water level inside +0.05 m outside -0.25 m	1367
Surcharge load +3 kN/m^2	1346

Table I-3 Additional manual variations LS wall

The α factors are all manually recalculated by using the FORM iteration before the final calculation. As this is not the final design point, the influence factors slightly differ from the final output of Prob2B as visualised in Figure I-2. The original influence factors are included to define partial safety factors as well as the manual obtained influence factors for the geometrical variations and governing surcharge load variations (Table I-4). The α factors are used to define partial safety factors for all parameters as presented in the main report.

X_i	**α**
$E_{oed,moderately\ packed\ sand}$	0.15
$G_{densely\ packed\ sand}$	0.50
$\varphi_{moderately\ packed\ sand}$	0.22
$\varphi_{densely\ packed\ sand}$	0.72
$\gamma_{sat,densely\ packed\ sand}$	-0.33
$\gamma_{unsat,moderately\ packed\ sand}$	0.24
Retaining height	0.05

Water level	0.06
Surcharge load	0.04

Table I-4 α factors including additional parameters

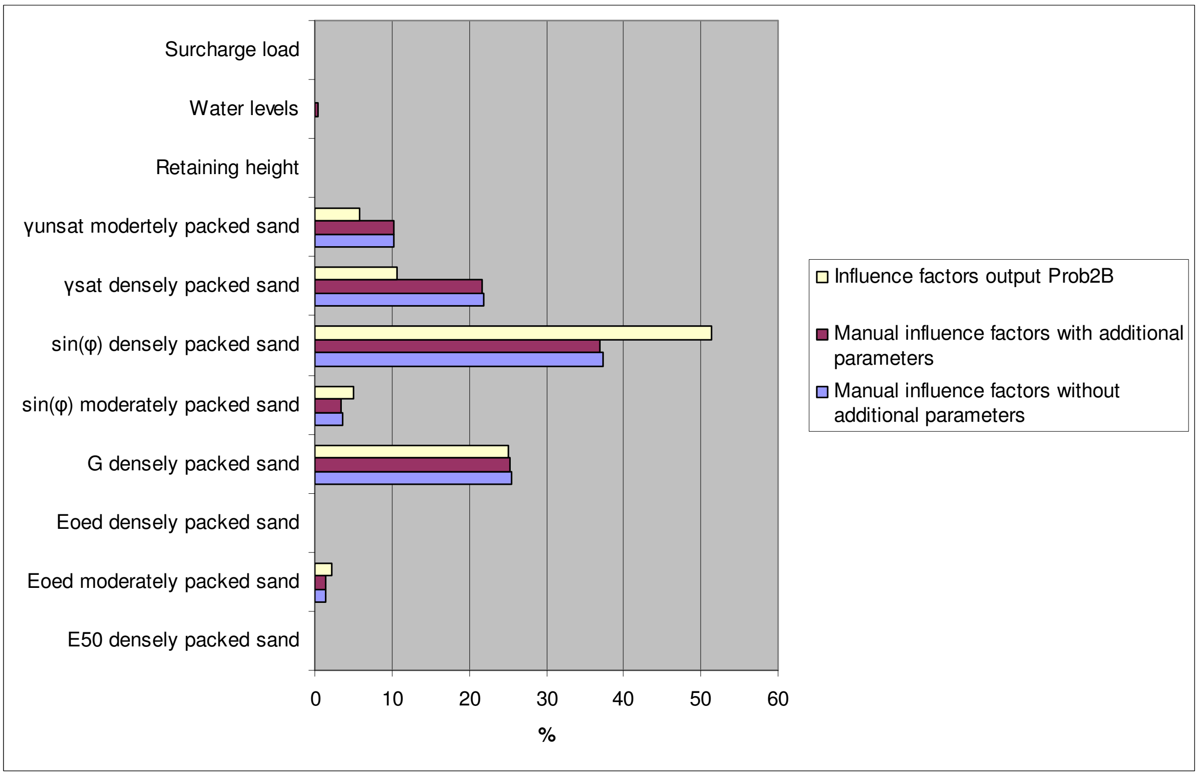

Figure I-2 Influence parameters on reliability beta = 3.78

I.1.3 Soil mechanical failure (ULS)

In the design point the three other parameters are varied manually in order to define α factors for these parameters as well. The results of the manual variation calculations are given in Table I-5.

Variation	**MSF [-]**
No variation (design point)	1.152
Retaining height +0.35 m	1.114
Water level inside +0.05 m outside -0.25 m	1.119
Surcharge load +3 kN/m^2	1.158

Table I-5 Additional manual variations LS soil

The α factors are all manually recalculated by using the FORM iteration before the final calculation. As this is not the final design point, the influence factors slightly differ from the final output of Prob2B as visualised in Figure I-3. The original influence factors are included to define partial safety factors as well as the manual obtained influence factors for the geometrical variations and governing surcharge load variations (Table I-6). The α factors are used to define partial safety factors for all parameters as presented in the main report.

X_i	**α**
$E_{50,\text{densely packed sand}}$	0.56
$E_{oed,\text{densely packed sand}}$	0.00
$G_{,\text{densely packed sand}}$	0.00

$\sin(\varphi)_{densely\ packed\ sand}$	0.82
$\gamma_{sat,\ densely\ packed\ sand}$	-0.13
Retaining height	0.08
Water level	0.07
Surcharge load	-0.01

Table I-6 α factors including additional parameters

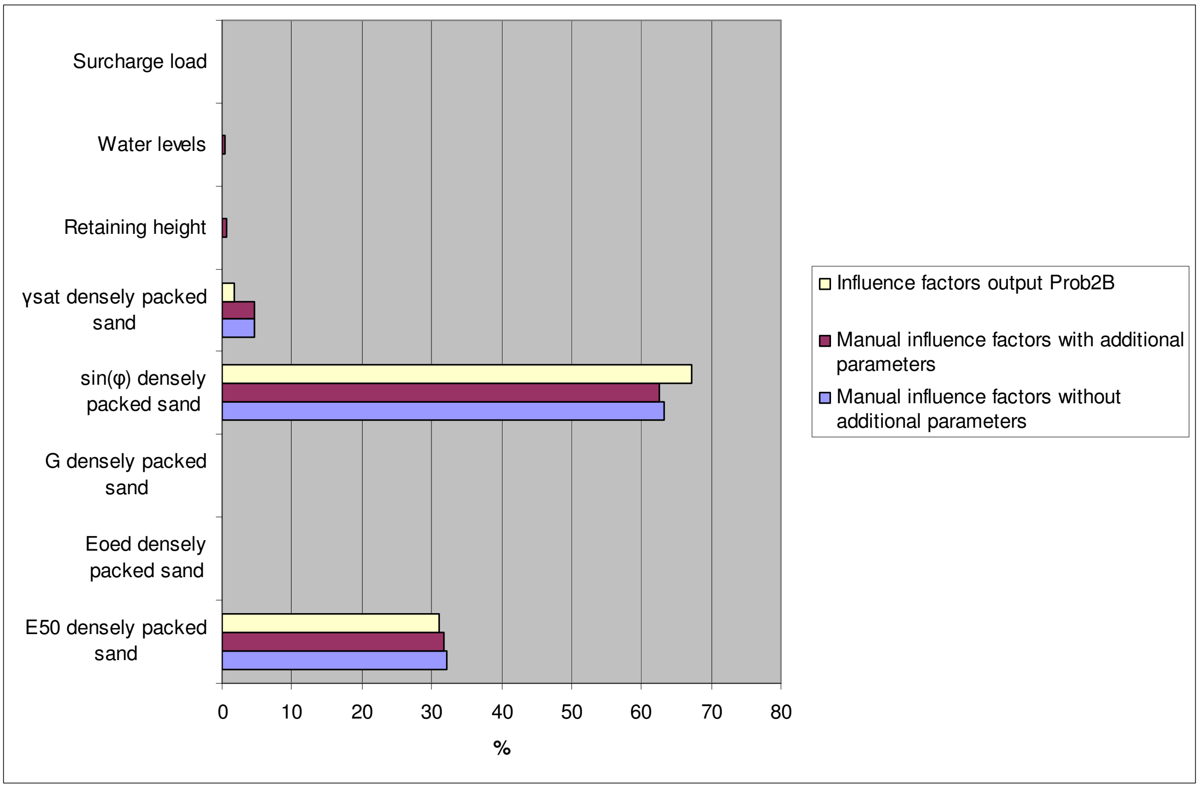

Figure I-3 Influence parameters on reliability beta = 3.1

I.1.4 Excessive deformations (SLS)

In the design point the three other parameters are varied manually in order to define α factors for these parameters as well. The results of the manual variation calculations are given in Table I-7.

Variation	δ_{max} [m]
No variation (design point)	-0.122
Retaining height +0.35 m	-0.142
Water level inside +0.05 m outside -0.25 m	-0.136
Surcharge load +3 kN/m^2	-0.126

Table I-7 Additional manual variations LS anchor

The α factors are all manually recalculated by using the results of the FORM iteration before the final calculation. As this is not the final design point, the influence factors differ from the final output of Prob2B as visualised in Figure I-1. The original influence factors are included to define partial safety factors as well as the manual obtained influence factors for the geometrical variations and governing surcharge load variations (Table I-8). For the LS excessive deformations it is clear that the influence of the variations in governing retaining height and water level are not negligible, although their influence is still limited. It is however uncertain what the reliability index in this case is, because β is based on the probabilistic calculation without the additional parameters. It is assumed that this difference in reliability is small as the influence of the additional parameters is not dominant with respect to the other parameters (for instance φ). The α factors are used to define partial safety factors for all parameters as presented in the main report.

X_i	α
$G_{moderate\ clay}$	0.06
$G_{densely\ packed\ sand}$	0.49
$\sin(\varphi)_{moderately\ packed\ sand}$	0.11
$\sin(\varphi)_{densely\ packed\ sand}$	0.75
$\gamma_{sat,moderate\ clay}$	0.05
$\gamma_{sat,densely\ packed\ sand}$	-0.42
Retaining height	0.18
Water level	0.13
Surcharge load	0.03

Table I-8 α factors including additional parameters

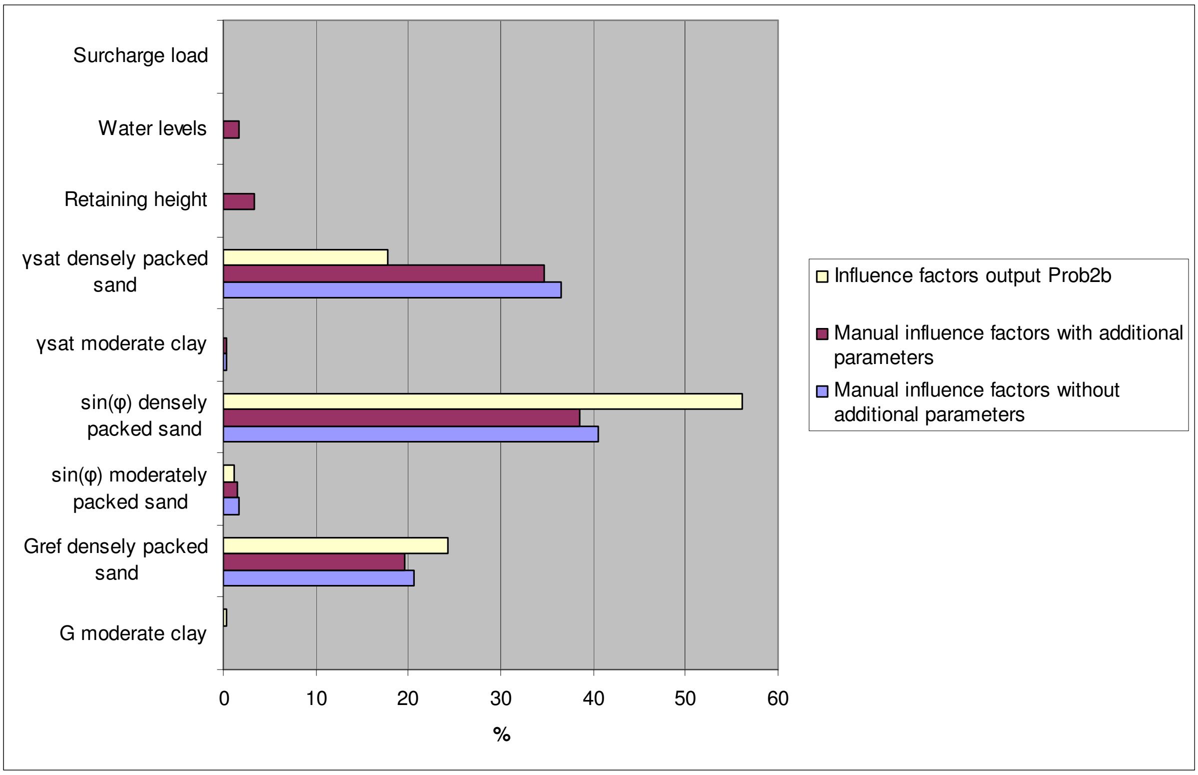

Figure I-4 Influence parameters on reliability beta = 2.8

J. Appendix - Output first calculations elongated anchored sheet-pile

This Appendix presents the calculation results of the first exploratory calculations for each failure mechanism for the first elongated benchmark. Based on these calculations several parameters are eliminated from the final calculation.

J.1.1 Anchor failure (ULS)

The output of the first calculation is shown in Table J-1 and Figure J-1.

Number of calculations (FORM): 97				
β: 3.539				
P_f: 2.006*10^{-4}				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
D_a	0.032	0.07	0.04	[m]
$f_{y,steel}$	0.07	0.35	366500	[kN/m^2]
EA_a	0.07	0.25	13480	[kN/m]
$C_{moderate\ clay}$	0.8	0.01	7.99	[kPa]
$E_{50,moderate\ clay}$	0.3	0.00	6577.00	[kPa]
$E_{50,moderately\ packed\ sand}$	0.3	0.00	66440	[kPa]
$E_{50,densely\ packed\ sand}$	0.3	0.00	99100	[kPa]
$E_{oed,moderate\ clay}$	0.3	0.00	4933	[kPa]
$E_{oed,moderately\ packed\ sand}$	0.3	0.00	66440	[kPa]
$E_{oed,densely\ packed\ sand}$	0.3	0.19	99100	[kPa]
$G_{moderate\ clay}$	0.3	0.00	6046	[kPa]
$G_{moderately\ packed\ sand}$	0.3	0.00	83050	[kPa]
$G_{densely\ packed\ sand}$	0.3	-0.33	123900	[kPa]
$m_{moderate\ clay}$	0.2	-0.01	1.05	[-]
$m_{moderately\ packed\ sand}$	0.2	0.07	0.51	[-]
$m_{densely\ packed\ sand}$	0.2	0.05	0.49	[-]
$R_{int,moderate\ clay}$	0.2	0.08	0.61	[-]
$R_{int,moderately\ packed\ sand}$	0.2	-0.07	0.87	[-]
$R_{int,densely\ packed\ sand}$	0.2	-0.03	0.88	[-]
$\sin(\varphi)_{moderate\ clay}$	0.18	0.18	0.43	[-]
$\sin(\varphi)_{moderately\ packed\ sand}$	0.18	0.57	0.35	[-]
$\sin(\varphi)_{densely\ packed\ sand}$	0.18	0.08	0.50	[-]
$\sin(\psi)_{moderately\ packed\ sand}$	0.18	-0.05	0.05	[-]
$\sin(\psi)_{densely\ packed\ sand}$	0.18	0.03	0.10	[-]
$\gamma_{sat,moderate\ clay}$	0.05	0.26	16.92	[kN/m^3]
$\gamma_{sat,moderately\ packed\ sand}$	0.05	0.42	20.03	[kN/m^3]
$\gamma_{sat,densely\ packed\ sand}$	0.05	0.06	20.74	[kN/m^3]
$\gamma_{unsat,moderately\ packed\ sand}$	0.05	0.16	17.92	[kN/m^3]
$d_{AZ36\text{-}700N}$	0.03	0.00	0.71	[kN/m]
$w_{AZ36\text{-}700N}$	0.04	0.00	1.81	[kN/m]
$G_{eq,AZ36\text{-}700N}$	0.07	0.00	2692000	[kN/m^2/m]

calc.	Z-value
1	316.90
97	8.01

Table J-1 Output calculation 1 (LS anchor - elongated)

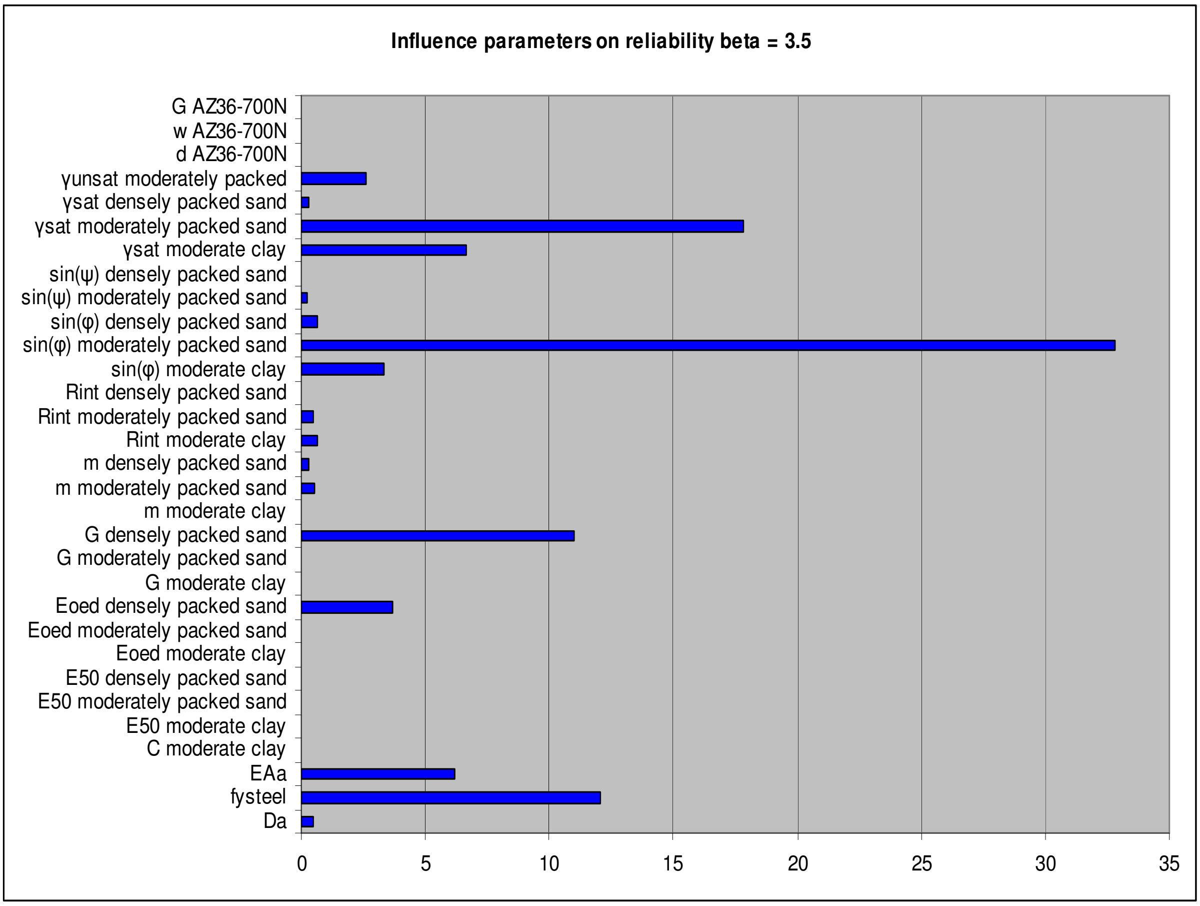

Figure J-1 Influence in % on reliability calculation 1 (LS anchor - elongated)

J.1.2 Wall failure (ULS)

The output of the first calculation is shown in Table J-2 and Figure J-2.

Number of calculations (FORM): 166				
β: 4.004				
P_f: 3.117*10^{-5}				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
EA_a	0.07	-0.03	14320	[kN/m]
$C_{moderate\ clay}$	0.8	0.13	12.36	[kPa]
$E_{50,moderate\ clay}$	0.3	0.08	6148	[kPa]
$E_{50,moderately\ packed\ sand}$	0.3	0.00	60760	[kPa]
$E_{50,densely\ packed\ sand}$	0.3	0.00	76870	[kPa]
$E_{oed,moderate\ clay}$	0.3	0.00	4597	[kPa]
$E_{oed,moderately\ packed\ sand}$	0.3	0.00	60760	[kPa]
$E_{oed,densely\ packed\ sand}$	0.3	0.00	76870	[kPa]
$G_{moderate\ clay}$	0.3	0.00	5652	[kPa]
$G_{moderately\ packed\ sand}$	0.3	0.15	75940	[kPa]
$G_{densely\ packed\ sand}$	0.3	0.47	96090	[kPa]
$m_{moderate\ clay}$	0.2	-0.01	1.01	[-]
$m_{moderately\ packed\ sand}$	0.2	0.02	0.51	[-]
$m_{densely\ packed\ sand}$	0.2	-0.04	0.49	[-]
$R_{int,moderate\ clay}$	0.2	0.01	0.63	[-]
$R_{int,moderately\ packed\ sand}$	0.2	-0.03	0.94	[-]

$R_{int,densely\ packed\ sand}$	0.2	0.01	0.90	[-]
$sin(\varphi)_{moderate\ clay}$	0.18	0.11	0.46	[-]
$sin(\varphi)_{moderately\ packed\ sand}$	0.18	0.32	0.45	[-]
$sin(\varphi)_{densely\ packed\ sand}$	0.18	0.65	0.26	[-]
$sin(\psi)_{moderately\ packed\ sand}$	0.18	-0.04	0.05	[-]
$sin(\psi)_{densely\ packed\ sand}$	0.18	-0.05	0.10	[-]
$\gamma_{sat,moderate\ clay}$	0.05	0.20	17.02	[kN/m^3]
$\gamma_{sat,moderately\ packed\ sand}$	0.05	0.00	20.15	[kN/m^3]
$\gamma_{sat,densely\ packed\ sand}$	0.05	-0.29	19.44	[kN/m^3]
$\gamma_{unsat,moderately\ packed\ sand}$	0.05	0.19	18.03	[kN/m^3]
$d_{AZ36-700N}$	0.03	-0.02	0.70	[kN/m]
$w_{AZ36-700N}$	0.04	-0.06	1.82	[kN/m]
$G_{eq,AZ36-700N}$	0.07	-0.01	2724000	[kN/m^2/m]
$W_{AZ36-700N}$	0.04	0.05	0.00	[m^3/m]
$f_{y,steel}$	0.07	0.13	386400	[kN/m^2]

calc.	Z-value
1	779.10
166	-1.00

Table J-2 Output calculation 1 (LS wall - elongated)

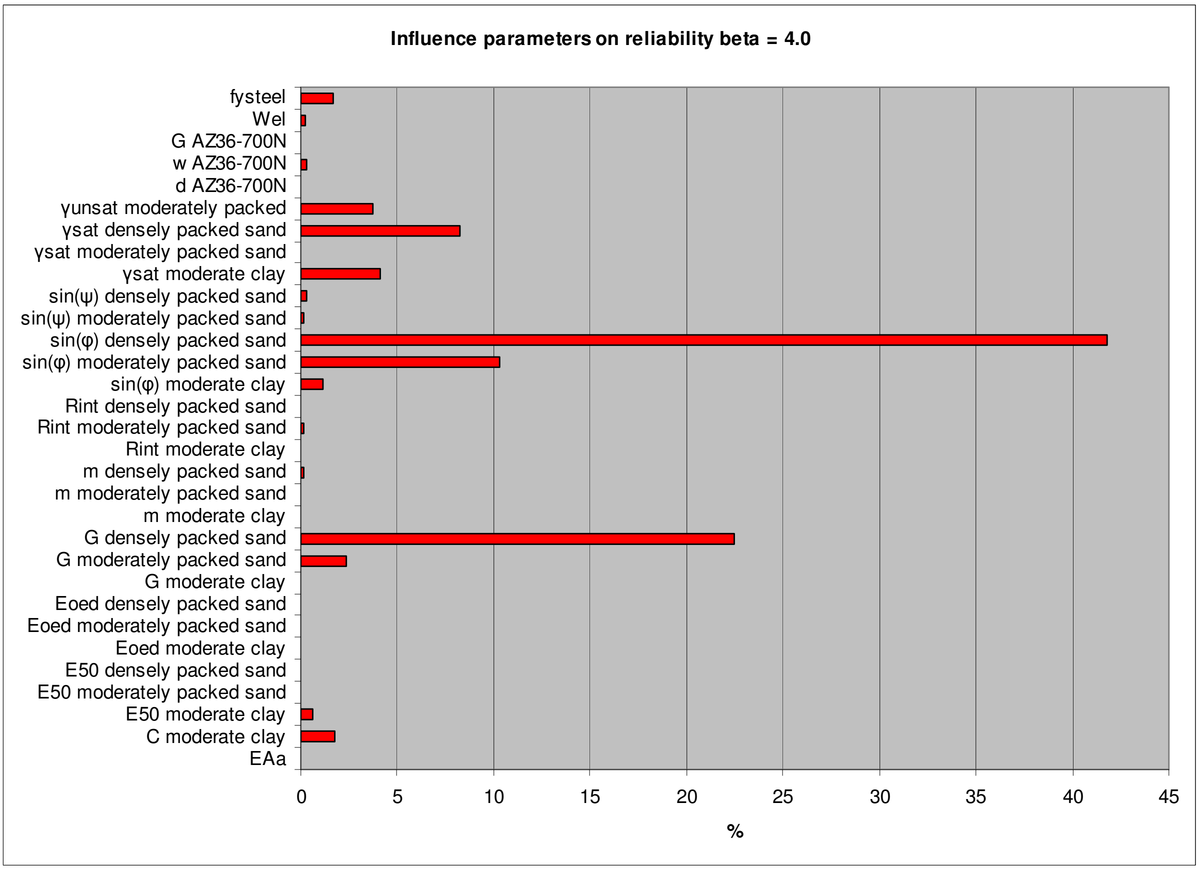

Figure J-2 Influence in % on reliability calculation 1 (LS wall- elongated)

J.1.3 Soil mechanical failure (ULS)

The output of the first four calculations is shown in Table J-3 until Table J-6 and Figure J-3 till Figure J-6.

Number of calculations (FORM) : 64				
β: 4.259				
P_f: $1.026 \cdot 10^{-5}$				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
EA_a	0.07	0.03	14220	[kN/m]
$C_{moderate\ clay}$	0.8	0.13	7.78	[kPa]
$\sin(\varphi)_{moderate\ clay}$	0.18	0.08	0.48	[-]
$\sin(\varphi)_{moderately\ packed\ sand}$	0.18	0.09	0.60	[-]
$\sin(\varphi)_{densely\ packed\ sand}$	0.18	0.98	0.26	[-]
$d_{AZ36\text{-}700N}$	0.03	-0.03	0.71	[kN/m]
$w_{AZ36\text{-}700N}$	0.04	0.03	1.81	[kN/m]
$G_{AZ36\text{-}700N}$	0.07	-0.03	2674000	[kN/m²/m]

calc.	Z-value	
1	0.20	
64	0.03	**MSF = 1.13**

Table J-3 Output calculation 1 (LS soil - elongated)

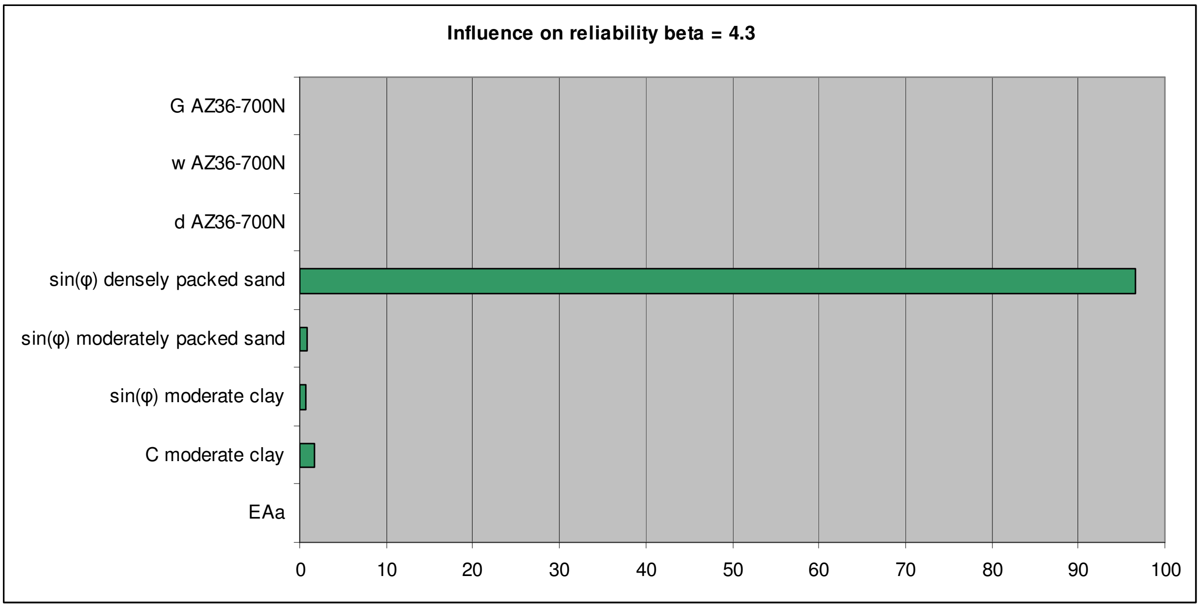

Figure J-3 Influence in % on reliability calculation 1 (LS soil - elongated)

Number of calculations (FORM): 67				
β: 3.884				
P_f: $5.132 \cdot 10^{-5}$				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
$E_{50,moderate\ clay}$	0.3	0.00	6650	[kPa]
$E_{50,moderately\ packed\ sand}$	0.3	0.01	64570	[kPa]
$E_{50,densely\ packed\ sand}$	0.3	0.00	90080	[kPa]
$E_{oed,moderate\ clay}$	0.3	0.00	4988	[kPa]
$E_{oed,moderately\ packed\ sand}$	0.3	-0.02	64570	[kPa]

$E_{oed,densely\ packed\ sand}$	0.3	0.43	90080	[kPa]
$G_{moderate\ clay}$	0.3	-0.01	6113	[kPa]
$G_{moderately\ packed\ sand}$	0.3	0.03	80710	[kPa]
$G_{densely\ packed\ sand}$	0.3	0.01	112600	[kPa]
$\sin(\varphi)_{densely\ packed\ sand}$	0.18	0.90	0.24	[-]

calc.	Z-value	
1	0.19	
67	0.00	MSF = 1.10

Table J-4 Output calculation 2 (LS soil - elongated)

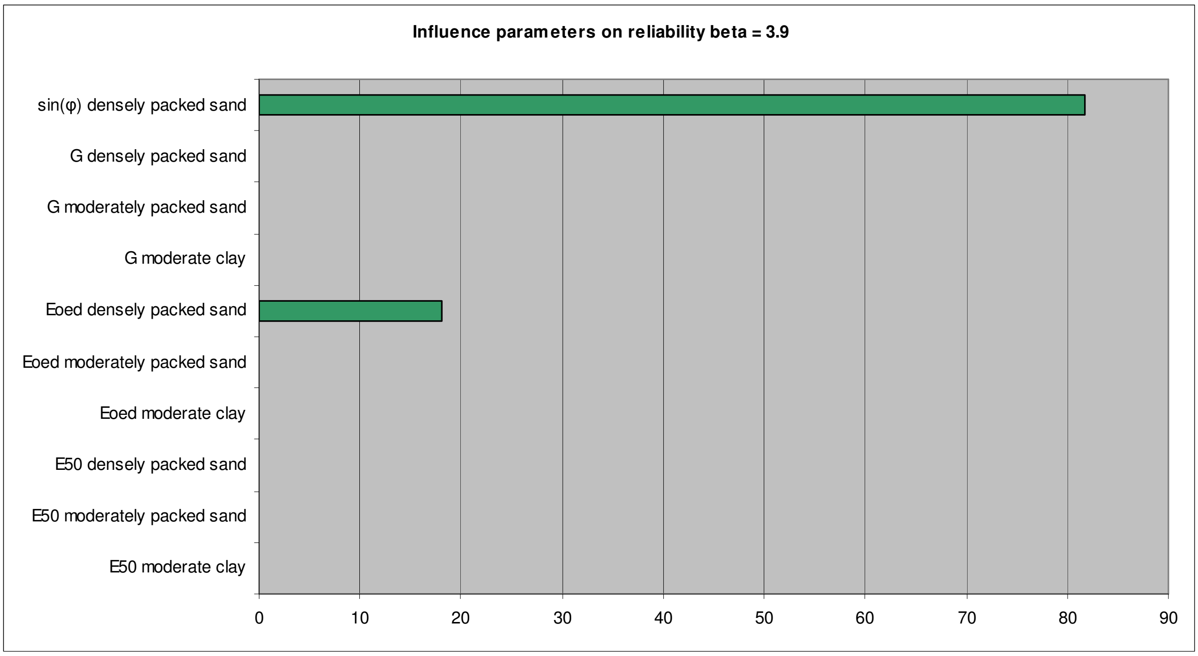

Figure J-4 Influence in % on reliability calculation 2 (LS soil - elongated)

Number of calculations (FORM: 97				
β: 4.200				
P_f: $1.338*10^{-5}$				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
$m_{moderate\ clay}$	0.2	0.02	1.02	[-]
$m_{moderately\ packed\ sand}$	0.2	0.11	0.44	[-]
$m_{densely\ packed\ sand}$	0.2	0.17	0.49	[-]
$R_{int,moderate\ clay}$	0.2	0.10	0.65	[-]
$R_{int,moderately\ packed\ sand}$	0.2	0.10	0.81	[-]
$R_{int,densely\ packed\ sand}$	0.2	0.10	0.85	[-]
$\sin(\varphi)_{densely\ packed\ sand}$	0.18	0.96	0.27	[-]

calc.	Z-value	
1	0.06	
97	0.11	MSF = 1.21

Table J-5 Output calculation 3 (LS soil - elongated)

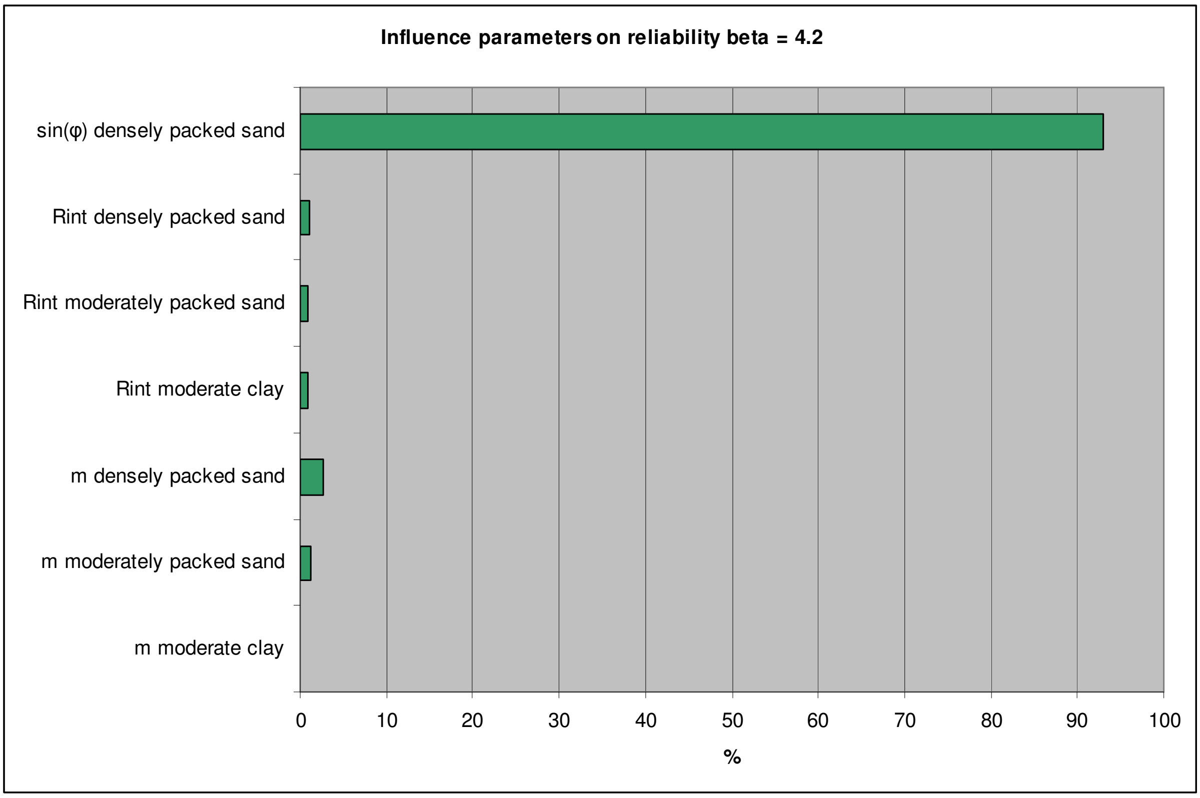

Figure J-5 Influence in % on reliability calculation 3 (LS soil - elongated)

Number of calculations (FORM) : 161				
β: 3.772				
P_f: $8.096 \cdot 10^{-5}$				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
$\sin(\varphi)_{densely\ packed\ sand}$	0.18	0.92	0.27	[-]
$\sin(\psi)_{moderately\ packed\ sand}$	0.18	0.06	0.05	[-]
$\sin(\psi)_{densely\ packed\ sand}$	0.18	0.14	0.10	[-]
$\gamma_{sat,moderate\ clay}$	0.05	0.12	17.19	[kN/m^3]
$\gamma_{sat,moderately\ packed\ sand}$	0.05	0.00	20.54	[kN/m^3]
$\gamma_{sat,densely\ packed\ sand}$	0.05	-0.32	20.37	[kN/m^3]
$\gamma_{unsat,moderately\ packed\ sand}$	0.05	0.08	18.38	[kN/m^3]

calc.	Z-value	
1	0.14	
161	0.07	MSF = 1.17

Table J-6 Output calculation 4 (LS soil - elongated)

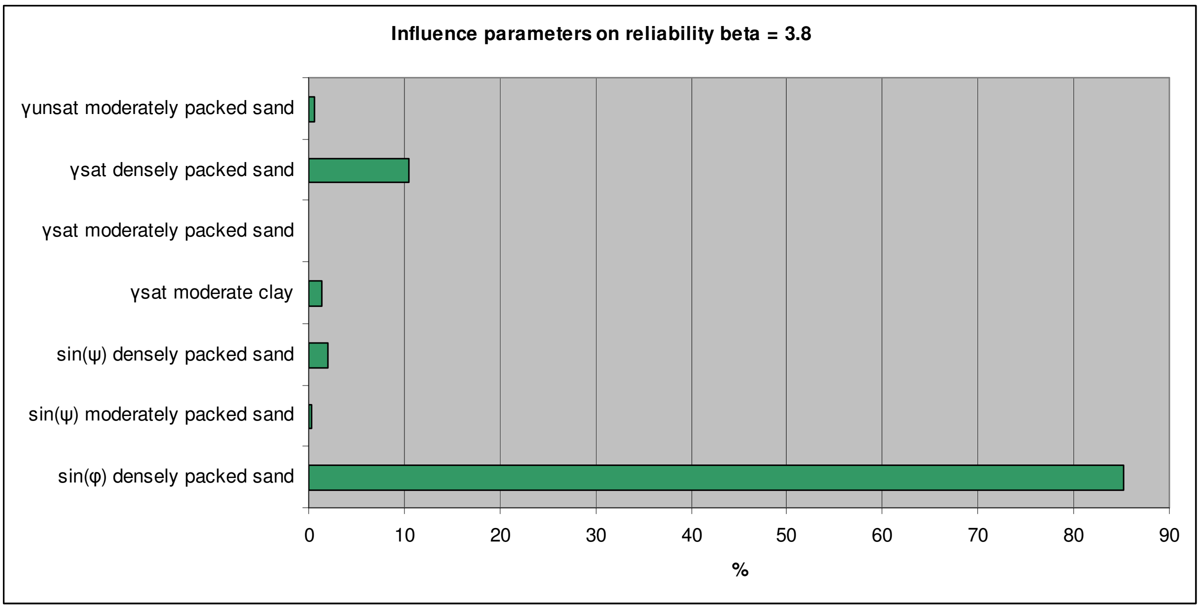

Figure J-6 Influence in % on reliability calculation 4 (LS soil - elongated)

J.1.4 Excessive deformations (SLS)

The output of the first calculation is shown in Table J-7 and Figure J-7.

Number of calculations (FORM): 125				
β: 2.696				
P_f: 3.508*10^{-3}				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
EA_a	0.07	-0.02	14210	[kN/m]
$C_{moderate\ clay}$	0.8	0.11	7.55	[kPa]
$E_{50,moderate\ clay}$	0.3	0.21	5768	[kPa]
$E_{50,moderately\ packed\ sand}$	0.3	0.00	65790	[kPa]
$E_{50,densely\ packed\ sand}$	0.3	0.41	90180	[kPa]
$E_{oed,moderate\ clay}$	0.3	0.00	4327	[kPa]
$E_{oed,moderately\ packed\ sand}$	0.3	0.00	65790	[kPa]
$E_{oed,densely\ packed\ sand}$	0.3	0.00	90180	[kPa]
$G_{moderate\ clay}$	0.3	0.00	5303	[kPa]
$G_{moderately\ packed\ sand}$	0.3	0.00	82240	[kPa]
$G_{densely\ packed\ sand}$	0.3	0.00	112700	[kPa]
$m_{moderate\ clay}$	0.2	0.00	1.02	[-]
$m_{moderately\ packed\ sand}$	0.2	-0.02	0.50	[-]
$m_{densely\ packed\ sand}$	0.2	-0.06	0.50	[-]
$R_{int,moderate\ clay}$	0.2	0.08	0.64	[-]
$R_{int,moderately\ packed\ sand}$	0.2	-0.05	0.92	[-]
$R_{int,densely\ packed\ sand}$	0.2	0.04	0.86	[-]
$\sin(\varphi)_{moderate\ clay}$	0.18	0.14	0.44	[-]
$\sin(\varphi)_{moderately\ packed\ sand}$	0.18	0.32	0.51	[-]
$\sin(\varphi)_{densely\ packed\ sand}$	0.18	0.63	0.40	[-]
$\sin(\psi)_{moderately\ packed\ sand}$	0.18	0.03	0.05	[-]
$\sin(\psi)_{densely\ packed\ sand}$	0.18	0.00	0.11	[-]
$\gamma_{sat,moderate\ clay}$	0.05	0.24	16.88	[kN/m^3]

$\gamma_{sat,moderately\ packed\ sand}$	0.05	0.21	20.44	[kN/m^3]
$\gamma_{sat,densely\ packed\ sand}$	0.05	-0.34	20.43	[kN/m^3]
$\gamma_{unsat,moderately\ packed\ sand}$	0.05	0.09	18.29	[kN/m^3]
$d_{AZ36-700N}$	0.03	0.05	0.70	[kN/m]
$w_{AZ36-700N}$	0.04	-0.04	1.82	[kN/m]
$G_{eq,AZ36-700N}$	0.07	0.04	2702000	[kN/m^2/m]

calc.	Z-value
1	0.0632
125	-0.0017

Table J-7 Output calculation 1 (LS deformations - elongated)

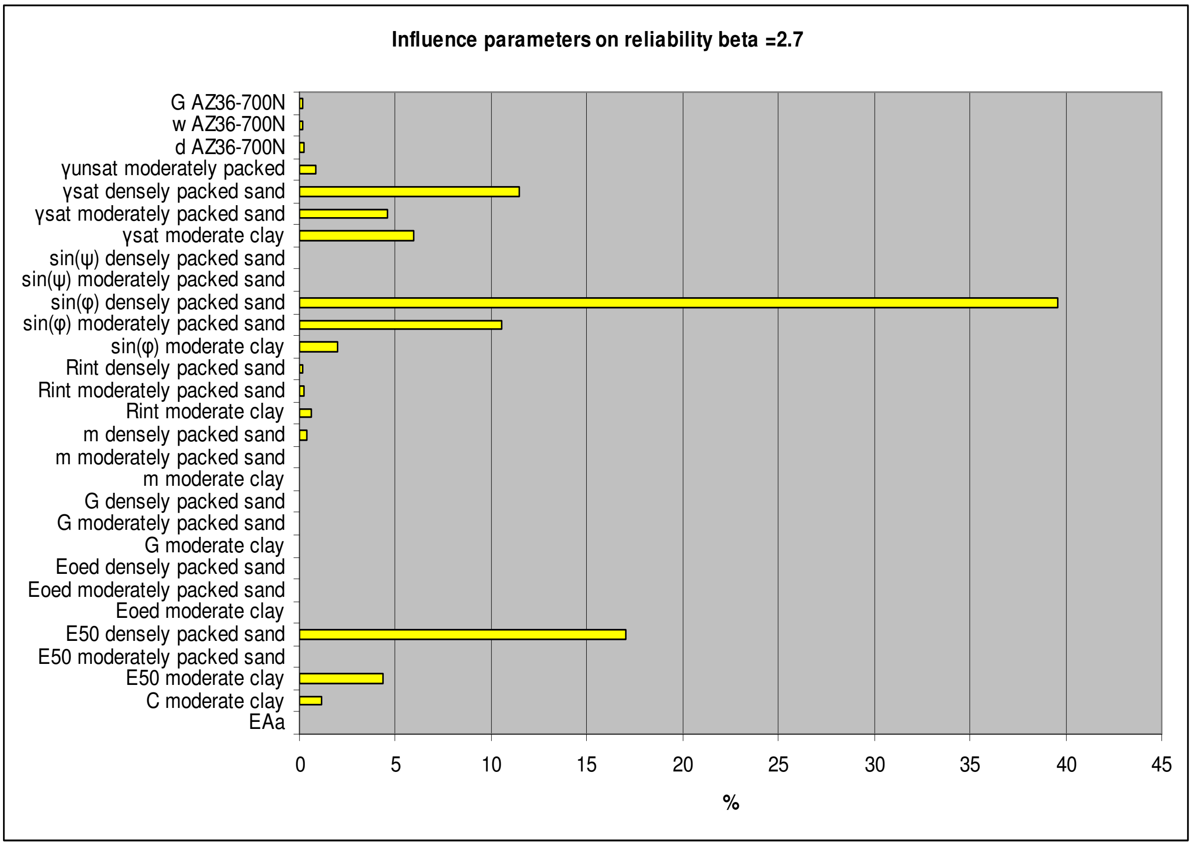

Figure J-7 Influence in % on reliability calculation 1 (LS deformations - elongated)

K. Appendix - Manual variation additional parameters elongated anchored sheet-pile

This Appendix presents the results of the manual variation and inclusion of the geometrical and load parameters in the probabilistic analysis and the derivation of their partial safety factor. This is done for each failure mechanism for the elongated benchmark 1 sheet-pile.

K.1.1 Anchor failure (ULS)

In the design point the three other parameters are varied manually in order to define α factors for the variations of these parameters in the governing situation as well. The results of the manual variation calculations are given in Table K-1.

Variation	$F_{anch,stage3}$ [kN]
No variation (design point)	545
Retaining height +0.35 m	560
Water level inside +0.05 m outside -0.25 m	562
Surcharge load +3 kN/m^2	553

Table K-1 Additional manual variations LS anchor - elongated

The α factors are all manually recalculated by using the FORM iteration before the final calculation. As this is not the final design point, the influence factors differ from the final output of Prob2B as visualised in Figure K-1. The original influence factors are included to define partial safety factors as well as the manual obtained influence factors for the geometrical variations and governing surcharge load variations (Table K-2). The α factors are used to define partial safety factors for all parameters as presented in the main report.

X_i	α
$f_{y,steel}$	0.42
EA_a	-0.05
$G_{densely\ packed\ sand}$	-0.29
$\varphi_{moderately\ packed\ sand}$	0.69
$\varphi_{densely\ packed\ sand}$	0.13
$\gamma_{sat,moderate\ clay}$	0.10
$\gamma_{sat,moderately\ packed\ sand}$	0.49
Retaining height	0.07
Water level	0.08
Surcharge load	0.04

Table K-2 α factors including additional parameters

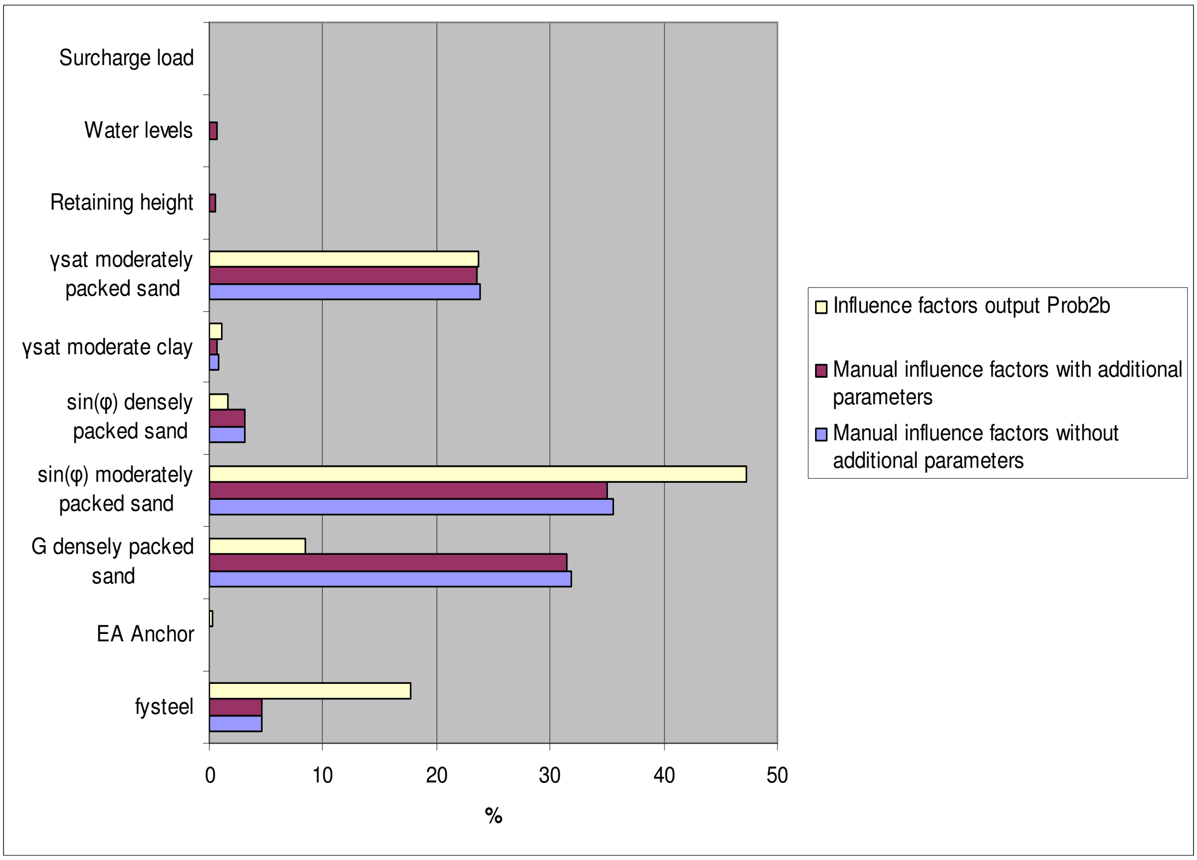

Figure K-1 Influence parameters on reliability beta = 4.09

K.1.2 Wall failure in bending (ULS)

In the design point the three other parameters are varied manually in order to define α factors for the variations of these parameters in the governing situation as well. The results of the manual variation calculations are given in Table K-3.

Variation	$M_{wall,stage3}$ [kNm]
No variation (design point)	1268
Retaining height +0.35 m	1400
Water level inside +0.05 m outside -0.25 m	1388
Surcharge load +3 kN/m^2	1262

Table K-3 Additional manual variations LS wall

The α factors are all manually recalculated by using the FORM iteration before the final calculation. As this is not the final design point, the influence factors differ from the final output of Prob2B as visualised in Figure K-2. The original influence factors are included to define partial safety factors as well as the manual obtained influence factors for the geometrical variations and governing surcharge load variations (Table K-4). The α factors are used to define partial safety factors for all parameters as presented in the main report.

X_i	α
$E_{50,densely\ packed\ sand}$	0.54
$E_{oed,\ densely\ packed\ sand}$	0.00
$G_{densely\ packed\ sand}$	0.00
$\sin(\varphi)_{moderately\ packed\ sand}$	0.05
$\sin(\varphi)_{densely\ packed\ sand}$	0.83

$\gamma_{sat,densely\ packed\ sand}$	0.12
Retaining height	0.11
Water level	0.10
Surcharge load	0.00

Table K-4 α factors including additional parameters

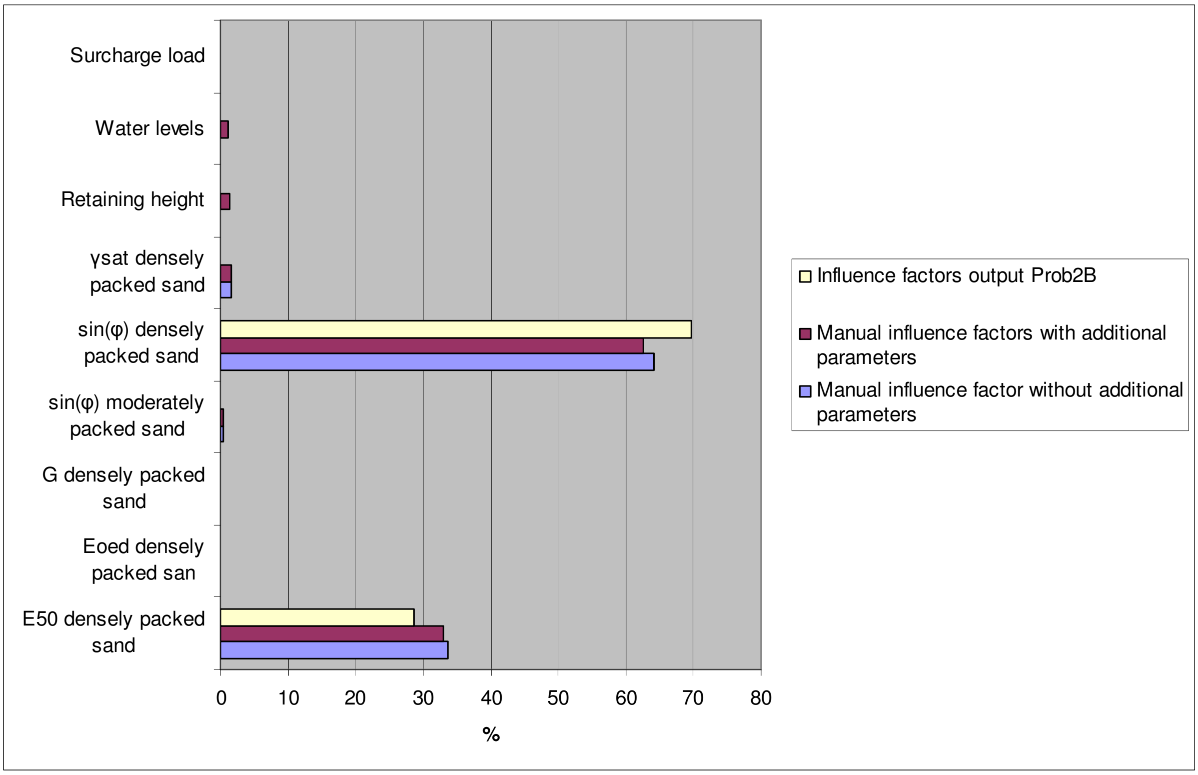

Figure K-2 Influence parameters on reliability beta = 3.96

K.1.3 Soil mechanical failure (ULS)

In the design point the three other parameters are varied manually in order to define α factors for these parameters as well. The results of the manual variation calculations and the first FORM operations are given in Table K-5.

Variation	MSF [-]
No variation (design point)	1.092
Retaining height +0.35 m	1.061
Water level inside +0.05 m outside -0.25 m	1.072
Surcharge load +3 kN/m^2	1.096

Table K-5 Additional manual variations LS soil - elongated

The α factors are all manually recalculated by using the FORM iteration before the final calculation. As this is not the final design point, the influence factors slightly differ from the final output of Prob2B as visualised in Figure K-3. The original influence factors are included to define partial safety factors as well as the manual obtained influence factors for the geometrical variations and governing surcharge load variations (Table K-6). The α factors are used to define partial safety factors for all parameters as presented in the main report.

X_i	α
$G_{densely\ packed\ sand}$	0.52
$\varphi_{densely\ packed\ sand}$	0.80
$\gamma_{sat,densely\ packed\ sand}$	-0.29
Retaining height	0.06
Water level	-0.01
Surcharge load	0.04

Table K-6 α factors including additional parameters

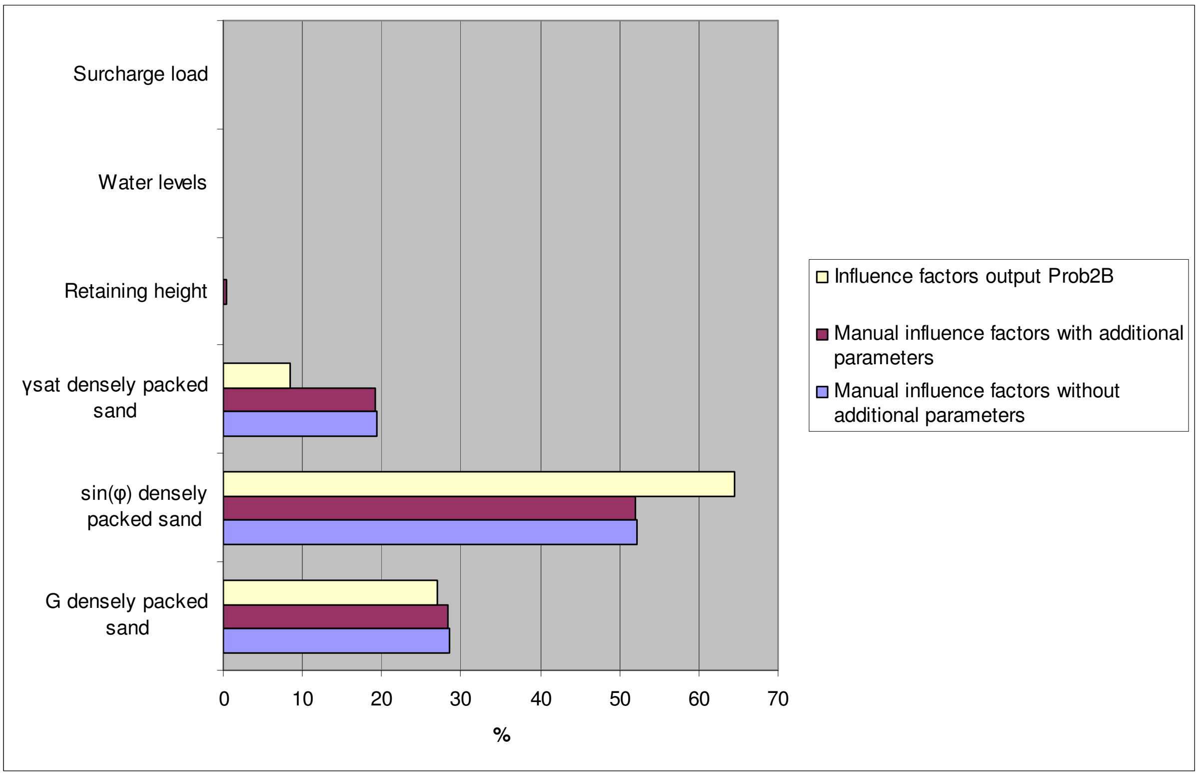

Figure K-3 Influence parameters on reliability beta = 3.38

K.1.4 Excessive deformations

In the design point the three other parameters are varied manually in order to define α factors for these parameters as well. The results of the manual variation calculations and the first FORM operations are given in Table K-7.

Variation	δ_{max} [m]
No variation (design point)	-0.120
Retaining height +0.35 m	-0.135
Water level inside +0.05 m outside -0.25 m	-0.135
Surcharge load +3 kN/m^2	-0.120

Table K-7 Additional manual variations LS anchor

The α factors are all manually recalculated by using the results of the FORM iteration before the final calculation. As this is not the final design point, the influence factors slightly differ from the final output of Prob2B as visualised in Figure K-4. The original influence factors are included to define partial safety factors as well as the manual obtained influence factors for the geometrical variations and governing surcharge load variations (Table K-8).

For the LS excessive deformations it is clear that the influence of the variations in governing retaining height and water level is small. It is however uncertain what the reliability index in this case is, because β is based on the probabilistic calculation without the additional parameters. It is assumed that this difference in reliability is small as the influence of the additional parameters is not dominant with respect to the other parameters (for instance φ). The α factors are used to define partial safety factors for all parameters as presented in the main report.

X_i	α
$E_{50,moderate\ clay}$	0.07
$E_{50,densely\ packed\ sand}$	0.52
$\varphi_{moderately\ packed\ sand}$	0.14
$\varphi_{densely\ packed\ sand}$	0.75
$\gamma_{sat,moderate\ clay}$	0.06
$\gamma_{sat,moderately\ packed\ sand}$	0.08
$\gamma_{sat,densely\ packed\ sand}$	-0.36
Retaining height	0.12
Water level	0.12
Surcharge load	0.00

Table K-8 α factors including additional parameters

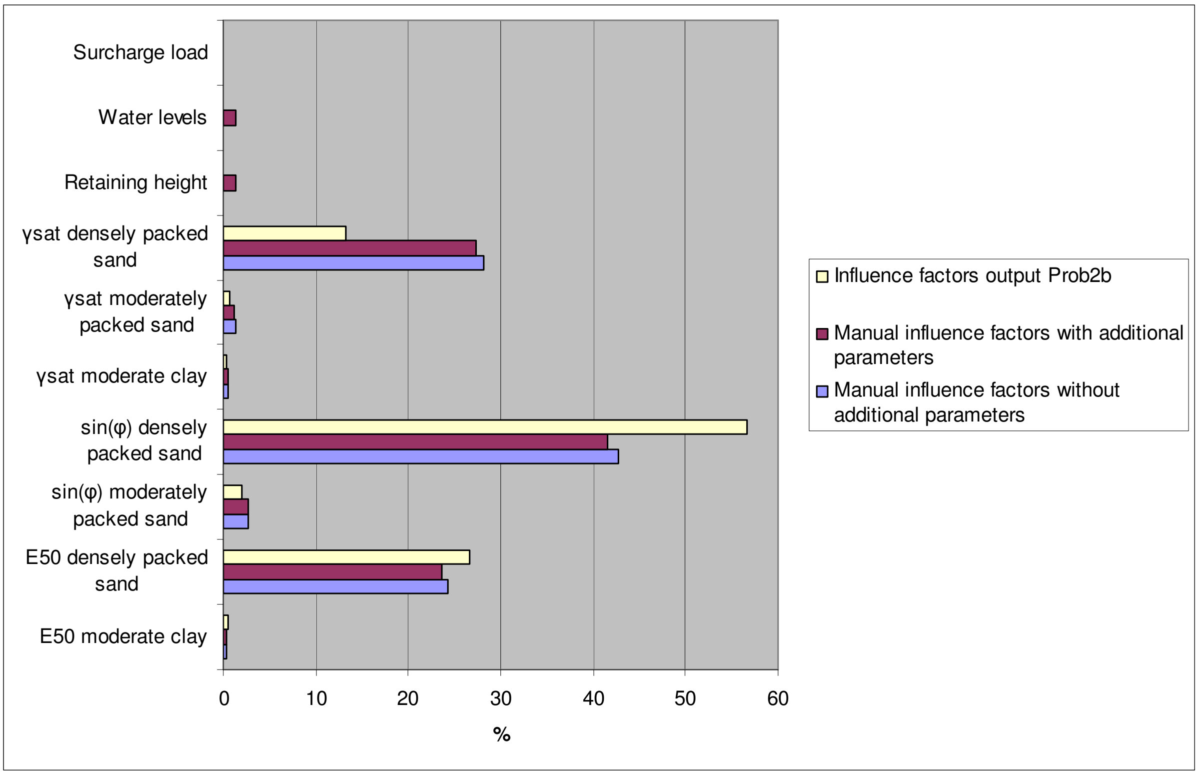

Figure K-4 Influence parameters on reliability beta = 2.69

L. Appendix - Output first calculations quay wall with relieving floor

This Appendix presents the calculation results of the first exploratory calculation for each failure mechanism for the second benchmark. Based on these calculations several parameters are eliminated from the final calculation.

L.1.1 Anchor failure (ULS)

All parameters are included in one calculation. The output is shown in Table L-1. Furthermore the influence of each parameter on the reliability in percentages (α^2*100) is given in Figure L-1.

Number of calculations (FORM): 385				
β: 4.040				
P_f: 2.670*10^{-5}				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
D_a	0.032	0.09	0.05	[m]
$f_{y,steel}$	0.07	0.50	344400	[kN/m^2]
$EA_{anchor1}$	0.07	0.40	468800	[kN/m]
$EA_{anchor2}$	0.07	0.00	523400	[kN/m]
$C_{clay\ 1}$	0.8	0.01	11.34	[kPa]
$C_{clay\ 2}$	0.8	0.03	9.81	[kPa]
$E_{50,clay\ 1}$	0.3	0.00	14210	[kPa]
$E_{50,clay\ 2}$	0.3	0.00	10460	[kPa]
$E_{50,moderately\ packed\ sand}$	0.3	0.00	67140	[kPa]
$E_{50,silty\ moderately\ packed\ sand}$	0.3	0.00	27000	[kPa]
$E_{50,pleistocene\ sand}$	0.3	0.00	70900	[kPa]
$E_{oed,clay\ 1}$	0.3	0.00	7106	[kPa]
$E_{oed,clay\ 2}$	0.3	0.00	5270	[kPa]
$E_{oed,moderately\ packed\ sand}$	0.3	0.00	67140	[kPa]
$E_{oed,silty\ moderately\ packed\ sand}$	0.3	0.00	27000	[kPa]
$E_{oed,pleistocene\ sand}$	0.3	0.00	70900	[kPa]
$G_{clay\ 1}$	0.3	0.10	29570	[kPa]
$G_{clay\ 2}$	0.3	0.06	17430	[kPa]
$G_{moderately\ packed\ sand}$	0.3	-0.19	83970	[kPa]
$G_{silty\ moderately\ packed\ sand}$	0.3	0.29	17970	[kPa]
$G_{pleistocene\ sand}$	0.3	0.18	103400	[kPa]
$m_{clay\ 1}$	0.2	0.02	1.02	[-]
$m_{clay\ 2}$	0.2	-0.02	1.01	[-]
$m_{moderately\ packed\ sand}$	0.2	-0.03	0.51	[-]
$m_{silty\ moderately\ packed\ sand}$	0.2	0.01	0.50	[-]
$m_{pleistocene\ sand}$	0.2	-0.01	0.51	[-]
$R_{int,clay\ 1}$	0.2	-0.02	0.67	[-]
$R_{int,clay\ 2}$	0.2	0.01	0.67	[-]
$R_{int,moderately\ packed\ sand}$	0.2	-0.04	0.92	[-]
$R_{int,silty\ moderately\ packed\ sand}$	0.2	0.00	0.89	[-]
$R_{int,pleistocene\ sand}$	0.2	0.02	0.86	[-]
$\sin(\varphi)_{clay\ 1}$	0.18	0.01	0.45	[-]
$\sin(\varphi)_{clay\ 2}$	0.18	0.04	0.39	[-]
$\sin(\varphi)_{moderately\ packed\ sand}$	0.18	0.07	0.69	[-]
$\sin(\varphi)_{silty\ moderately\ packed\ sand}$	0.18	0.15	0.45	[-]

$\sin(\varphi)_{\text{pleistocene sand}}$	0.18	0.53	0.37	[-]
$\sin(\psi)_{\text{moderately packed sand}}$	0.18	-0.03	0.05	[-]
$\sin(\psi)_{\text{pleistocene sand}}$	0.18	0.02	0.12	[-]
$\gamma_{\text{sat,clay 1}}$	0.05	-0.04	18.52	[kN/m^3]
$\gamma_{\text{sat,clay 2}}$	0.05	0.06	17.05	[kN/m^3]
$\gamma_{\text{sat,moderately packed sand}}$	0.05	0.00	22.89	[kN/m^3]
$\gamma_{\text{sat,silty moderately packed sand}}$	0.05	-0.19	19.92	[kN/m^3]
$\gamma_{\text{sat,pleistocene sand}}$	0.05	-0.20	20.23	[kN/m^3]
$\gamma_{\text{unsat,moderately packed sand}}$	0.05	-0.15	20.60	[kN/m^3]
$d_{\text{1420/18 AU20}}$	0.03	0.02	1.53	[kN/m]
$w_{\text{1420/18 AU20}}$	0.03	0.02	2.68	[kN/m]
$G_{\text{eq,1420/18 AU20}}$	0.07	-0.01	1768000	[kN/m^2/m]

calc.	Z-value	
1	471	
385	-1.47	

Table L-1 Output calculation 1 (LS Anchor 1)

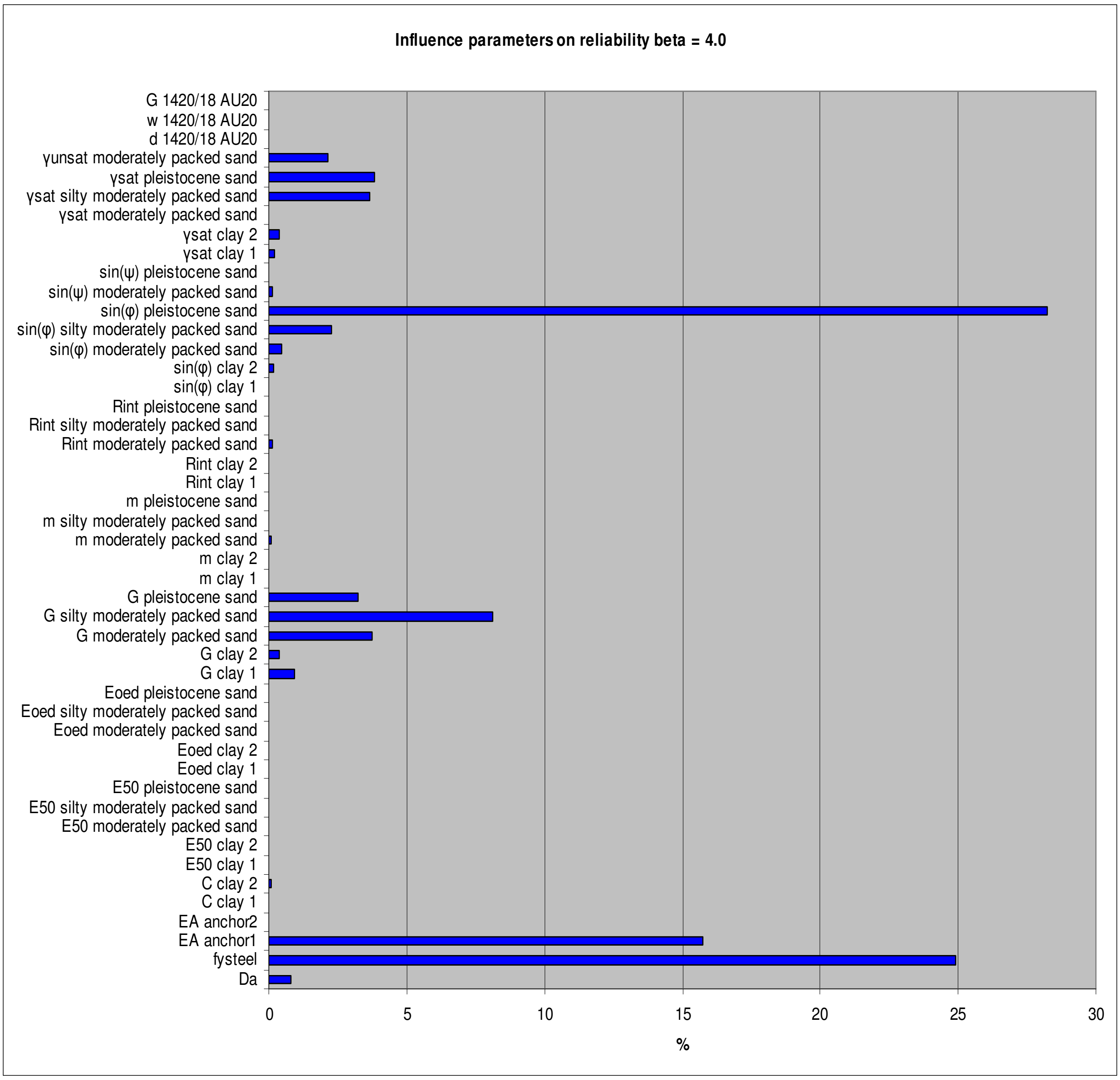

Figure L-1 Influence in % from parameters on reliability calculation 1 (LS Anchor 1)

From Figure L-1 it can be concluded that many parameters are not relevant in the probabilistic calculation. They are eliminated and not included in the final calculation.

L.1.2 Anchor 2 failure (ULS)

All parameters are included in one calculation. The output is shown in Table L-2. Furthermore the influence of each parameter on the reliability in percentages (α^2*100) is given in Figure L-2.

Number of calculations (FORM): 1030				
B: 3.127				
P_f: 8.841*10^{-4}				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
D_a	0.032	0.06	0.05	[m]
$f_{y,steel}$	0.07	0.25	379000	[kN/m^2]
$EA_{anchor1}$	0.07	-0.02	527000	[kN/m]
$EA_{anchor2}$	0.07	0.22	499800	[kN/m]
$C_{clay\ 1}$	0.8	0.01	10.65	[kPa]
$C_{clay\ 2}$	0.8	0.06	9.54	[kPa]
$E_{50,clay\ 1}$	0.3	0.00	14460	[kPa]
$E_{50,clay\ 2}$	0.3	0.00	10290	[kPa]
$E_{50,moderately\ packed\ sand}$	0.3	0.00	56010	[kPa]
$E_{50,silty\ moderately\ packed\ sand}$	0.3	0.00	27550	[kPa]
$E_{50,pleistocene\ sand}$	0.3	0.00	73180	[kPa]
$E_{oed,clay\ 1}$	0.3	0.00	7230	[kPa]
$E_{oed,clay\ 2}$	0.3	0.12	5188	[kPa]
$E_{oed,moderately\ packed\ sand}$	0.3	0.00	56010	[kPa]
$E_{oed,silty\ moderately\ packed\ sand}$	0.3	0.33	27550	[kPa]
$E_{oed,pleistocene\ sand}$	0.3	0.00	73180	[kPa]
$G_{clay\ 1}$	0.3	0.00	30080	[kPa]
$G_{clay\ 2}$	0.3	0.00	17150	[kPa]
$G_{moderately\ packed\ sand}$	0.3	0.13	70050	[kPa]
$G_{silty\ moderately\ packed\ sand}$	0.3	-0.23	18340	[kPa]
$G_{pleistocene\ sand}$	0.3	-0.69	106700	[kPa]
$m_{clay\ 1}$	0.2	-0.01	1.00	[-]
$m_{clay\ 2}$	0.2	0.01	1.00	[-]
$m_{moderately\ packed\ sand}$	0.2	0.00	0.50	[-]
$m_{silty\ moderately\ packed\ sand}$	0.2	0.00	0.49	[-]
$m_{pleistocene\ sand}$	0.2	0.03	0.49	[-]
$R_{int,clay\ 1}$	0.2	0.02	0.67	[-]
$R_{int,clay\ 2}$	0.2	0.01	0.65	[-]
$R_{int,moderately\ packed\ sand}$	0.2	0.00	0.88	[-]
$R_{int,silty\ moderately\ packed\ sand}$	0.2	0.00	0.89	[-]
$R_{int,pleistocene\ sand}$	0.2	0.05	0.90	[-]
$\sin(\varphi)_{clay\ 1}$	0.18	-0.01	0.46	[-]
$\sin(\varphi)_{clay\ 2}$	0.18	0.04	0.40	[-]
$\sin(\varphi)_{moderately\ packed\ sand}$	0.18	0.28	0.50	[-]
$\sin(\varphi)_{silty\ moderately\ packed\ sand}$	0.18	0.18	0.47	[-]
$\sin(\varphi)_{pleistocene\ sand}$	0.18	0.11	0.39	[-]
$\sin(\psi)_{moderately\ packed\ sand}$	0.18	-0.07	0.05	[-]
$\sin(\psi)_{pleistocene\ sand}$	0.18	0.06	0.12	[-]
$\gamma_{sat,clay\ 1}$	0.05	-0.02	18.51	[kN/m^3]
$\gamma_{sat,clay\ 2}$	0.05	0.09	17.06	[kN/m^3]
$\gamma_{sat,moderately\ packed\ sand}$	0.05	0.00	21.40	[kN/m^3]

$\gamma_{sat,silty\ moderately\ packed\ sand}$	0.05	-0.16	20.02	[kN/m^3]
$\gamma_{sat,pleistocene\ sand}$	0.05	0.10	20.00	[kN/m^3]
$\gamma_{unsat,moderately\ packed\ sand}$	0.05	0.18	19.25	[kN/m^3]
$d_{1420/18\ AU20}$	0.03	0.05	1.53	[kN/m]
$w_{1420/18\ AU20}$	0.03	-0.01	2.68	[kN/m]
$G_{eq,1420/18\ AU20}$	0.07	0.03	1757000	[kN/m^2/m]

calc.	Z-value	
1	449	
1030	14,90	

Table L-2 Output calculation 1 (LS Anchor 2)

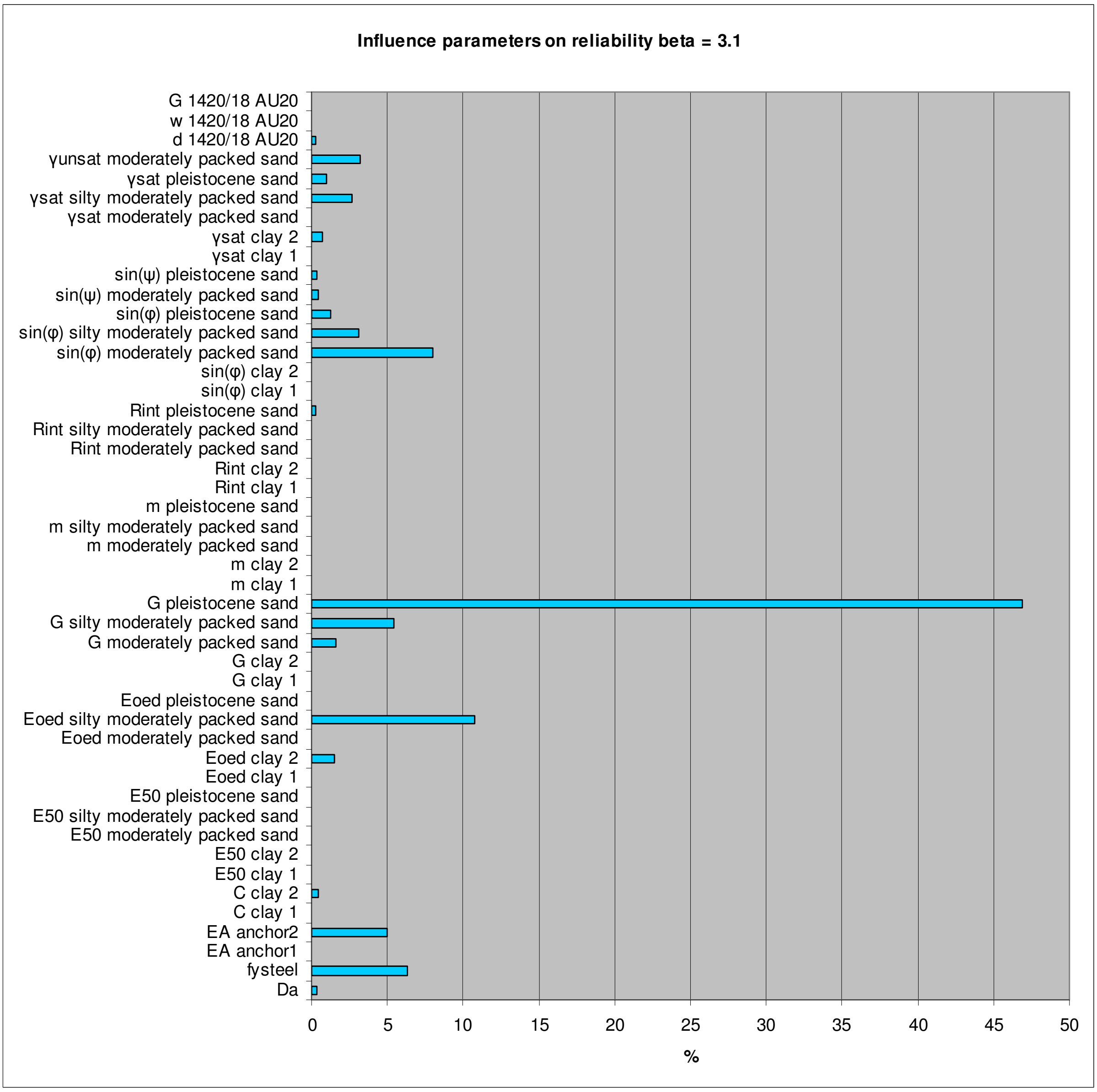

Figure L-2 Influence in % from parameters on reliability calculation 1 (LS Anchor 2)

From Figure L-2 it can be concluded that many parameters are not relevant in the probabilistic calculation. They are eliminated and not included in the final calculation.

L.1.3 Wall failure (ULS)

All parameters are included in one calculation. The output is shown in Table L-3. Furthermore the influence of each parameter on the reliability in percentages (α^2*100) is given in Figure L-3.

Number of calculations (FORM): 491				
β: 2.334E000				
P_f: 9.787*10^{-3}				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
$EA_{anchor1}$	0.07	-0.08	524800	[kN/m]
$EA_{anchor2}$	0.07	0.00	526200	[kN/m]
$C_{clay\ 1}$	0.8	0.02	10,58	[kPa]
$C_{clay\ 2}$	0.8	0.11	9,14	[kPa]
$E_{50,clay\ 1}$	0.3	0.00	14570	[kPa]
$E_{50,clay\ 2}$	0.3	0.11	10820	[kPa]
$E_{50,moderately\ packed\ sand}$	0.3	-0.01	59190	[kPa]
$E_{50,silty\ moderately\ packed\ sand}$	0.3	0.00	27400	[kPa]
$E_{50,pleistocene\ sand}$	0.3	0.00	72250	[kPa]
$E_{oed,clay\ 1}$	0.3	0.00	7285	[kPa]
$E_{oed,clay\ 2}$	0.3	0.00	5456	[kPa]
$E_{oed,moderately\ packed\ sand}$	0.3	-0.02	59190	[kPa]
$E_{oed,silty\ moderately\ packed\ sand}$	0.3	0.00	27400	[kPa]
$E_{oed,pleistocene\ sand}$	0.3	0.00	72250	[kPa]
$G_{clay\ 1}$	0.3	-0.07	30310	[kPa]
$G_{clay\ 2}$	0.3	0.00	18040	[kPa]
$G_{moderately\ packed\ sand}$	0.3	0.00	74030	[kPa]
$G_{silty\ moderately\ packed\ sand}$	0.3	-0.18	45630	[kPa]
$G_{pleistocene\ sand}$	0.3	0.46	105400	[kPa]
$m_{clay\ 1}$	0.2	0.00	1.02	[-]
$m_{clay\ 2}$	0.2	-0.04	1.01	[-]
$m_{moderately\ packed\ sand}$	0.2	-0.01	0.51	[-]
$m_{silty\ moderately\ packed\ sand}$	0.2	-0.01	0.50	[-]
$m_{pleistocene\ sand}$	0.2	0.02	0.50	[-]
$R_{int,clay\ 1}$	0.2	0.00	0.65	[-]
$R_{int,clay\ 2}$	0.2	0.06	0.65	[-]
$R_{int,moderately\ packed\ sand}$	0.2	0.05	0.90	[-]
$R_{int,silty\ moderately\ packed\ sand}$	0.2	0.05	0.89	[-]
$R_{int,pleistocene\ sand}$	0.2	-0.03	0.88	[-]
$\sin(\varphi)_{clay\ 1}$	0.18	0.00	0.46	[-]
$\sin(\varphi)_{clay\ 2}$	0.18	0.06	0.40	[-]
$\sin(\varphi)_{moderately\ packed\ sand}$	0.18	0.15	0.60	[-]
$\sin(\varphi)_{silty\ moderately\ packed\ sand}$	0.18	0.59	0.51	[-]
$\sin(\varphi)_{pleistocene\ sand}$	0.18	0.38	0.44	[-]
$\sin(\psi)_{moderately\ packed\ sand}$	0.18	-0.01	0.05	[-]
$\sin(\psi)_{pleistocene\ sand}$	0.18	0.10	0.13	[-]
$\gamma_{sat,clay\ 1}$	0.05	0.04	18.61	[kN/m^3]
$\gamma_{sat,clay\ 2}$	0.05	0.14	17.14	[kN/m^3]
$\gamma_{sat,moderately\ packed\ sand}$	0.05	0.00	21.89	[kN/m^3]
$\gamma_{sat,silty\ moderately\ packed\ sand}$	0.05	-0.32	20.31	[kN/m^3]
$\gamma_{sat,pleistocene\ sand}$	0.05	-0.09	20.43	[kN/m^3]
$\gamma_{unsat,moderately\ packed\ sand}$	0.05	0.00	19.70	[kN/m^3]
$d_{1420/18\ AU20}$	0.03	0.02	1.53	[kN/m]

$w_{1420/18\ AU20}$	0.03	0.00	2.67	[kN/m]
$G_{eq,1420/18\ AU20}$	0.07	-0.05	1774000	[kN/m^2/m]
$A_{1420/18\ AU20}$	0.03	-0.02	0.03	[m^2/m]
$W_{1420/18\ AU20}$	0.07	0.13	0.01	[m^3/m]
$f_{y,steel}$	0.07	0.17	386900	[kN/m^2]

calc.	Z-value	
1	161700	
491	6875	

Table L-3 Output calculation 1 (LS wall failure)

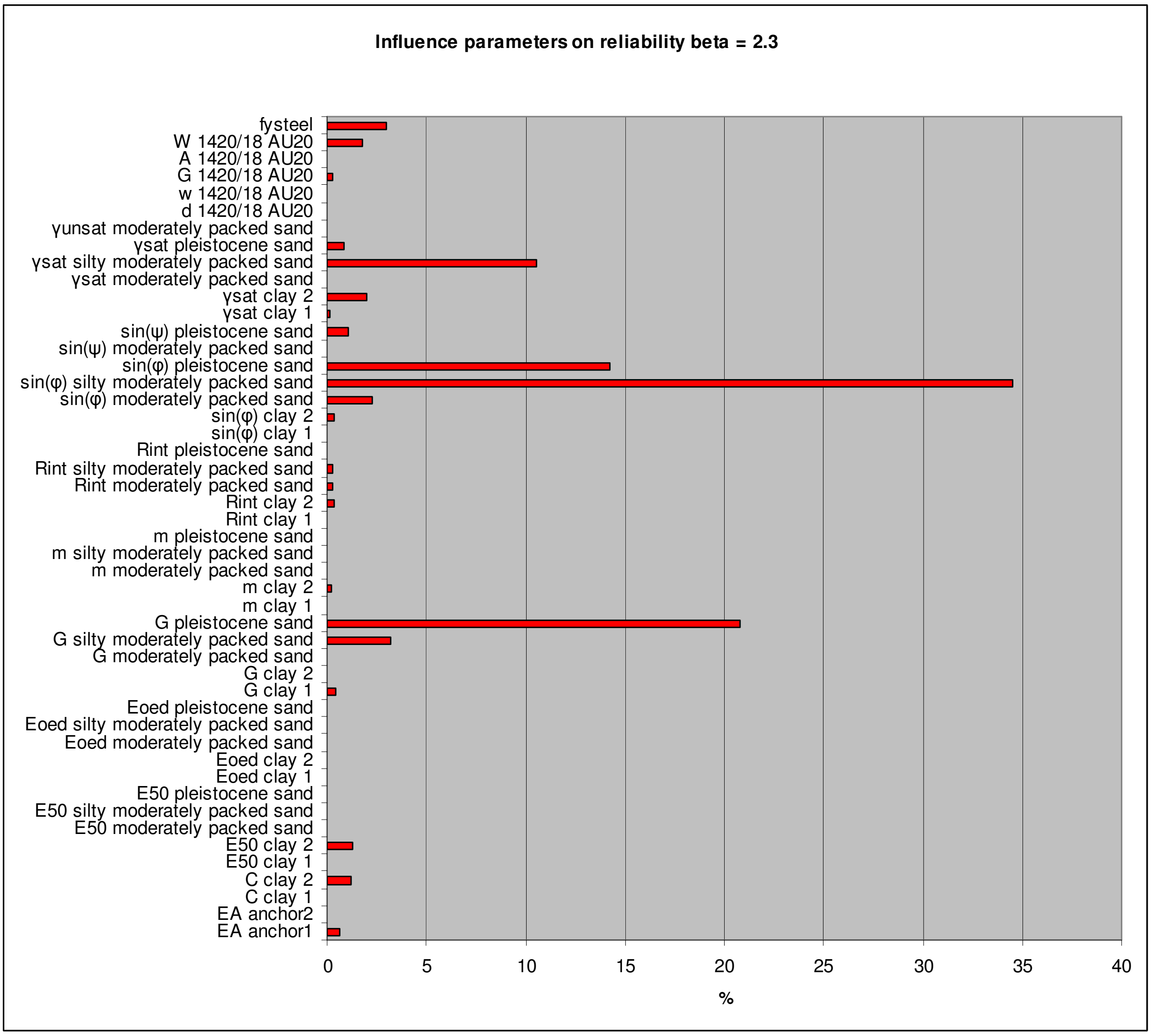

Figure L-3 Influence in % from parameters on reliability calculation 1 (LS wall)

From Figure L-3 it can be concluded that many parameters are not relevant in the probabilistic calculation. They are eliminated and not included in the final calculation.

L.1.4 Soil mechanical failure (ULS)

All parameters are included in the first calculation. The output is shown in Table L-4, including the value of MSF at which the design point was found. Figure L-4 shows the influence of the parameters on the reliability.

Number of calculations (FORM): 277				
β: 2.657				
P_f: $3.938 \cdot 10^{-3}$				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
$EA_{anchor1}$	0.07	0.01	521100	[kN/m]
$EA_{anchor2}$	0.07	0.01	528900	[kN/m]
$C_{clay\ 1}$	0.8	0.01	11.63	[kPa]
$C_{clay\ 2}$	0.8	-0.01	11.72	[kPa]
$E_{50,clay\ 1}$	0.3	0.00	16170	[kPa]
$E_{50,clay\ 2}$	0.3	0.01	10800	[kPa]
$E_{50,moderately\ packed\ sand}$	0.3	-0.01	57490	[kPa]
$E_{50,silty\ moderately\ packed\ sand}$	0.3	-0.12	29970	[kPa]
$E_{50,pleistocene\ sand}$	0.3	-0.01	68530	[kPa]
$E_{oed,clay\ 1}$	0.3	0.00	8088	[kPa]
$E_{oed,clay\ 2}$	0.3	0.06	5444	[kPa]
$E_{oed,moderately\ packed\ sand}$	0.3	0.04	57490	[kPa]
$E_{oed,silty\ moderately\ packed\ sand}$	0.3	-0.01	29960	[kPa]
$E_{oed,pleistocene\ sand}$	0.3	0.52	68530	[kPa]
$G_{clay\ 1}$	0.3	-0.17	33650	[kPa]
$G_{clay\ 2}$	0.3	0.00	18000	[kPa]
$G_{moderately\ packed\ sand}$	0.3	0.00	71910	[kPa]
$G_{silty\ moderately\ packed\ sand}$	0.3	0.00	49900	[kPa]
$G_{pleistocene\ sand}$	0.3	0.00	99960	[kPa]
$m_{clay\ 1}$	0.2	-0.02	0.99	[-]
$m_{clay\ 2}$	0.2	0.01	1.01	[-]
$m_{moderately\ packed\ sand}$	0.2	-0.04	0.51	[-]
$m_{silty\ moderately\ packed\ sand}$	0.2	0.02	0.49	[-]
$m_{pleistocene\ sand}$	0.2	0.00	0.50	[-]
$R_{int,clay\ 1}$	0.2	0.01	0.68	[-]
$R_{int,clay\ 2}$	0.2	0.00	0.69	[-]
$R_{int,moderately\ packed\ sand}$	0.2	0.00	0.89	[-]
$R_{int,silty\ moderately\ packed\ sand}$	0.2	-0.18	0.95	[-]
$R_{int,pleistocene\ sand}$	0.2	0.02	0.87	[-]
$\sin(\varphi)_{clay\ 1}$	0.18	0.02	0.47	[-]
$\sin(\varphi)_{clay\ 2}$	0.18	0.03	0.39	[-]
$\sin(\varphi)_{moderately\ packed\ sand}$	0.18	0.10	0.60	[-]
$\sin(\varphi)_{silty\ moderately\ packed\ sand}$	0.18	0.05	0.58	[-]
$\sin(\varphi)_{pleistocene\ sand}$	0.18	0.75	0.38	[-]
$\sin(\psi)_{moderately\ packed\ sand}$	0.18	0.01	0.05	[-]
$\sin(\psi)_{pleistocene\ sand}$	0.18	0.03	0.12	[-]
$\gamma_{sat,clay\ 1}$	0.05	0.03	18.76	[kN/m^3]
$\gamma_{sat,clay\ 2}$	0.05	0.06	17.08	[kN/m^3]
$\gamma_{sat,moderately\ packed\ sand}$	0.05	0.00	21.77	[kN/m^3]
$\gamma_{sat,silty\ moderately\ packed\ sand}$	0.05	-0.01	20.67	[kN/m^3]
$\gamma_{sat,pleistocene\ sand}$	0.05	-0.23	19.89	[kN/m^3]
$\gamma_{unsat,moderately\ packed\ sand}$	0.05	0.01	19.59	[kN/m^3]
$d_{1420/18\ AU20}$	0.03	0.01	1.54	[kN/m]

$w_{1420/18\ AU20}$	0.03	0.02	2.69	[kN/m]
$G_{eq,1420/18\ AU20}$	0.07	0.01	1755000	[kN/m^2/m]

calc.	Z-value	
1	1.11	
277	0.06	**MSF = 1.16**

Table L-4 Output calculation 1 (LS soil)

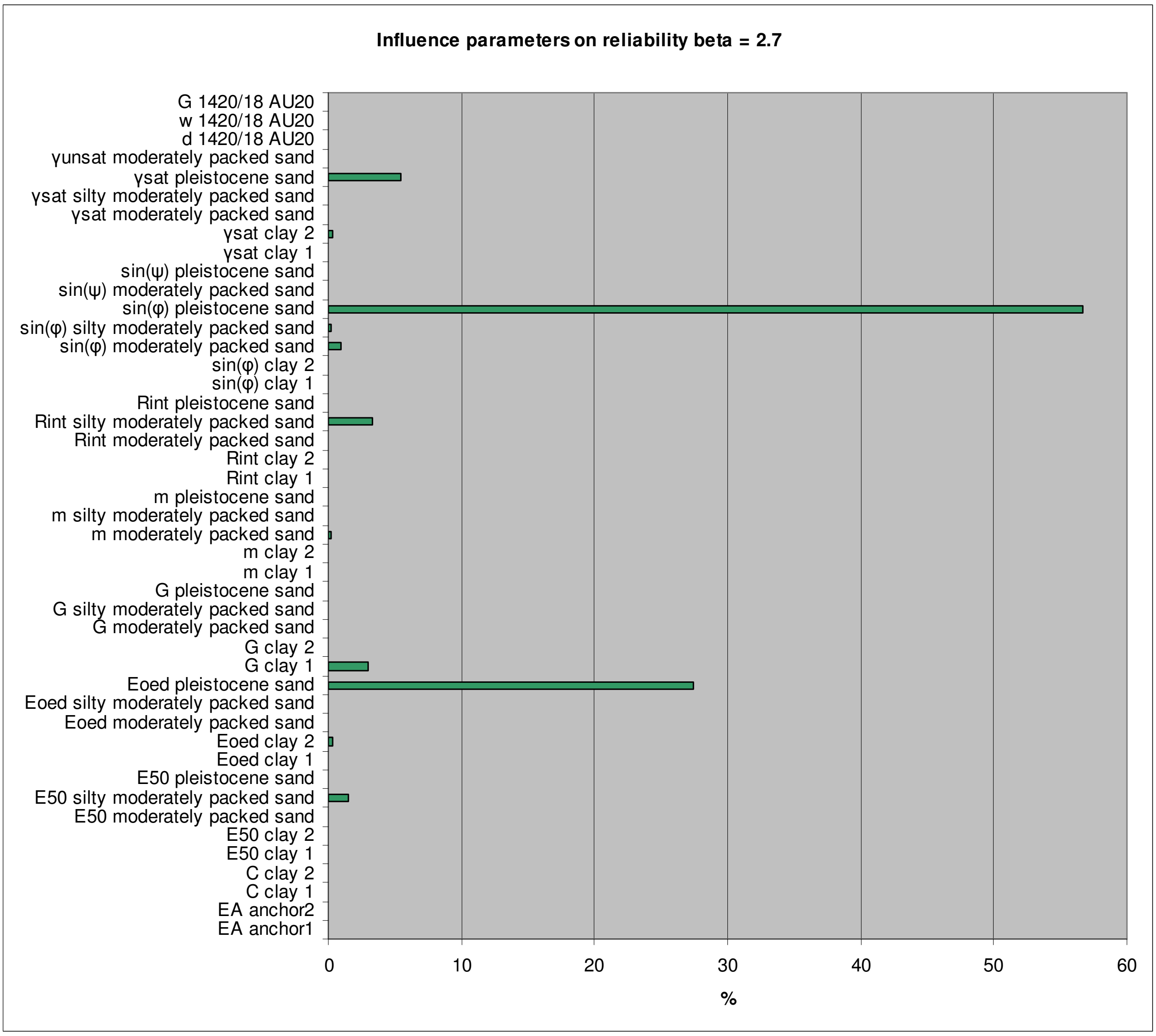

Figure L-4 Influence in % from parameters on reliability calculation 1 (LS soil)

From Figure L-4 it can be concluded that many parameters are not relevant in the probabilistic calculation. They are eliminated and not included in the final calculation.

L.1.5 Excessive Deformations (SLS)

All parameters are included in one calculation. The output is shown in Table L-5. Furthermore the influence of each parameter on the reliability in percentages (α^2*100) is given in Figure L-5.

Number of calculations (FORM): 369				
β: 2.061				
P_f: 1.964*10^{-2}				
Parameter (X)	**V = σ / μ**	**α**	**X* (design point)**	**Unit**
$EA_{anchor1}$	0.07	-0.05	525500	[kN/m]
$EA_{anchor2}$	0.07	0.03	523000	[kN/m]
$C_{clay\ 1}$	0.8	-0.07	12.48	[kPa]
$C_{clay\ 2}$	0.8	0.04	9.60	[kPa]
$E_{50,clay\ 1}$	0.3	0.00	14960	[kPa]
$E_{50,clay\ 2}$	0.3	0.14	10710	[kPa]
$E_{50,moderately\ packed\ sand}$	0.3	-0.08	61630	[kPa]
$E_{50,silty\ moderately\ packed\ sand}$	0.3	0.00	28260	[kPa]
$E_{50,pleistocene\ sand}$	0.3	0.00	73830	[kPa]
$E_{oed,clay\ 1}$	0.3	0.00	7479	[kPa]
$E_{oed,clay\ 2}$	0.3	0.00	5397	[kPa]
$E_{oed,moderately\ packed\ sand}$	0.3	-0.02	61630	[kPa]
$E_{oed,silty\ moderately\ packed\ sand}$	0.3	0.00	28260	[kPa]
$E_{oed,pleistocene\ sand}$	0.3	-0.05	73840	[kPa]
$G_{clay\ 1}$	0.3	-0.10	31120	[kPa]
$G_{clay\ 2}$	0.3	0.00	17840	[kPa]
$G_{moderately\ packed\ sand}$	0.3	0.00	77080	[kPa]
$G_{silty\ moderately\ packed\ sand}$	0.3	-0.23	47060	[kPa]
$G_{pleistocene\ sand}$	0.3	0.44	107700	[kPa]
$m_{clay\ 1}$	0.2	-0.01	1.00	[-]
$m_{clay\ 2}$	0.2	-0.05	1.02	[-]
$m_{moderately\ packed\ sand}$	0.2	0.03	0.50	[-]
$m_{silty\ moderately\ packed\ sand}$	0.2	-0.02	0.51	[-]
$m_{pleistocene\ sand}$	0.2	0.01	0.50	[-]
$R_{int,clay\ 1}$	0.2	-0.03	0.67	[-]
$R_{int,clay\ 2}$	0.2	0.01	0.66	[-]
$R_{int,moderately\ packed\ sand}$	0.2	-0.01	0.91	[-]
$R_{int,silty\ moderately\ packed\ sand}$	0.2	-0.01	0.88	[-]
$R_{int,pleistocene\ sand}$	0.2	0.04	0.89	[-]
$\sin(\varphi)_{clay\ 1}$	0.18	-0.09	0.45	[-]
$\sin(\varphi)_{clay\ 2}$	0.18	0.06	0.40	[-]
$\sin(\varphi)_{moderately\ packed\ sand}$	0.18	0.05	0.63	[-]
$\sin(\varphi)_{silty\ moderately\ packed\ sand}$	0.18	0.58	0.53	[-]
$\sin(\varphi)_{pleistocene\ sand}$	0.18	0.46	0.45	[-]
$\sin(\psi)_{moderately\ packed\ sand}$	0.18	-0.05	0.05	[-]
$\sin(\psi)_{pleistocene\ sand}$	0.18	0.00	0.13	[-]
$\gamma_{sat,clay\ 1}$	0.05	0.05	18.50	[kN/m^3]
$\gamma_{sat,clay\ 2}$	0.05	0.11	17.16	[kN/m^3]
$\gamma_{sat,moderately\ packed\ sand}$	0.05	0.00	21.95	[kN/m^3]
$\gamma_{sat,silty\ moderately\ packed\ sand}$	0.05	-0.31	20.46	[kN/m^3]
$\gamma_{sat,pleistocene\ sand}$	0.05	-0.14	20.51	[kN/m^3]
$\gamma_{unsat,moderately\ packed\ sand}$	0.05	0.00	19.75	[kN/m^3]
$d_{1420/18\ AU20}$	0.03	0.02	1.53	[kN/m]

$w_{1420/18\ AU20}$	0.03	-0.01	2.69	[kN/m]
$G_{eq,1420/18\ AU20}$	0.07	-0.02	1764000	[kN/m^2/m]

calc.	Z-value
1	0.0288
369	0.0023

Table L-5 Output calculation 1 (LS deformations)

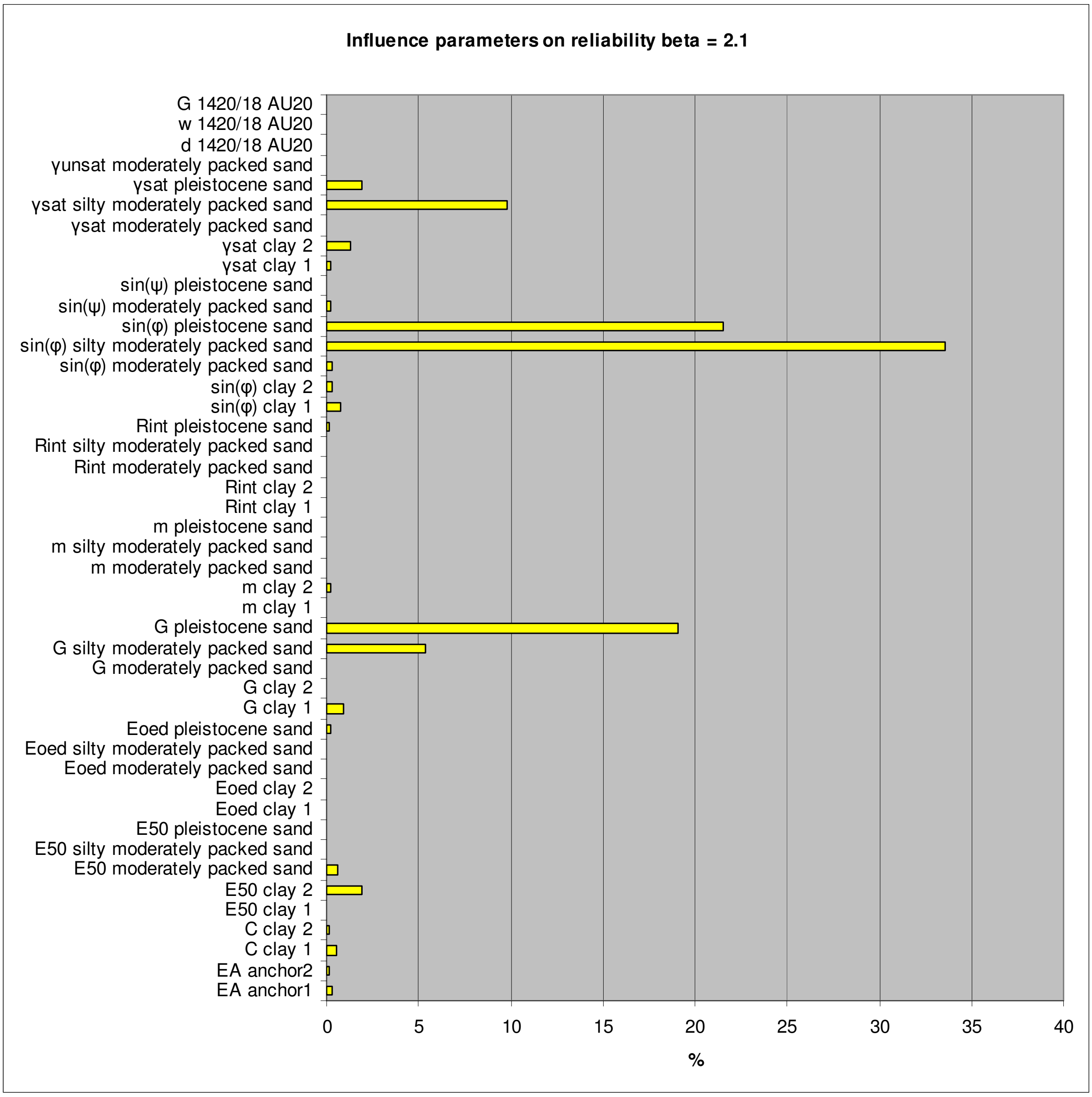

Figure L-5 Influence in % from parameters on reliability calculation 1 (LS deformations)

From Figure L-4 it can be concluded that many parameters are not relevant in the probabilistic calculation. They are eliminated and not included in the final calculation.

M. Appendix - Manual variation additional parameters quay wall with relieving floor

This Appendix presents the results of the manual variation and inclusion of the geometrical and load parameters in the probabilistic analysis and the derivation of their partial safety factor. This is done for each failure mechanism for the benchmark 2 quay wall.

M.1.1 Anchor 1 failure (ULS)

In the design point the three other parameters are varied manually in order to define α factors for these parameters as well. The results of the manual variation calculations are given in Table M-1.

Variation	$F_{anch2,stage4}$ [kN]
No variation (design point)	596
Retaining height +0.35 m	587
Water level inside +0.05 m outside -0.25 m	591
Surcharge load +3 kN/m^2	606

Table M-1 Additional manual variations LS anchor 1

The α factors are all manually recalculated by using the FORM iteration before the final calculation. As this is not the final design point, the influence factors differ from the final output of Prob2B as visualised in Figure M-1. The stiffness parameters of the lower sand layer get larger influence whereas the anchor parameters are less important in the manual calculation. The original influence factors are included to define partial safety factors as well as the manual obtained influence factors for the geometrical variations and governing surcharge load variations (Table M-2). These α factors are used to define partial safety factors for all parameters as presented in the main report. β is actually an overestimation of the situation, because the retaining height, water levels and surcharge load do also influence this index. This difference cannot be quantified, because the design point does not change from the original design point.

X_i	α
D_a	0.11
$f_{y,steel}$	0.61
$EA_{anchor1}$	0.47
$G_{moderately\ packed\ sand}$	-0.09
$G_{silty\ moderately\ packed\ sand}$	-0.19
$G_{pleistocene\ sand}$	-0.47
$\sin(\varphi)_{silty\ moderately\ packed\ sand}$	0.16
$\sin(\varphi)_{pleistocene\ sand}$	0.23
$\gamma_{sat,silty\ moderately\ packed\ sand}$	-0.23
$\gamma_{sat,pleistocene\ sand}$	0.00
$\gamma_{unsat,moderately\ packed\ sand}$	-0.03
Retaining height	-0.04
Water level	-0.02
Surcharge load	0.04

Table M-2 α factors including additional parameters

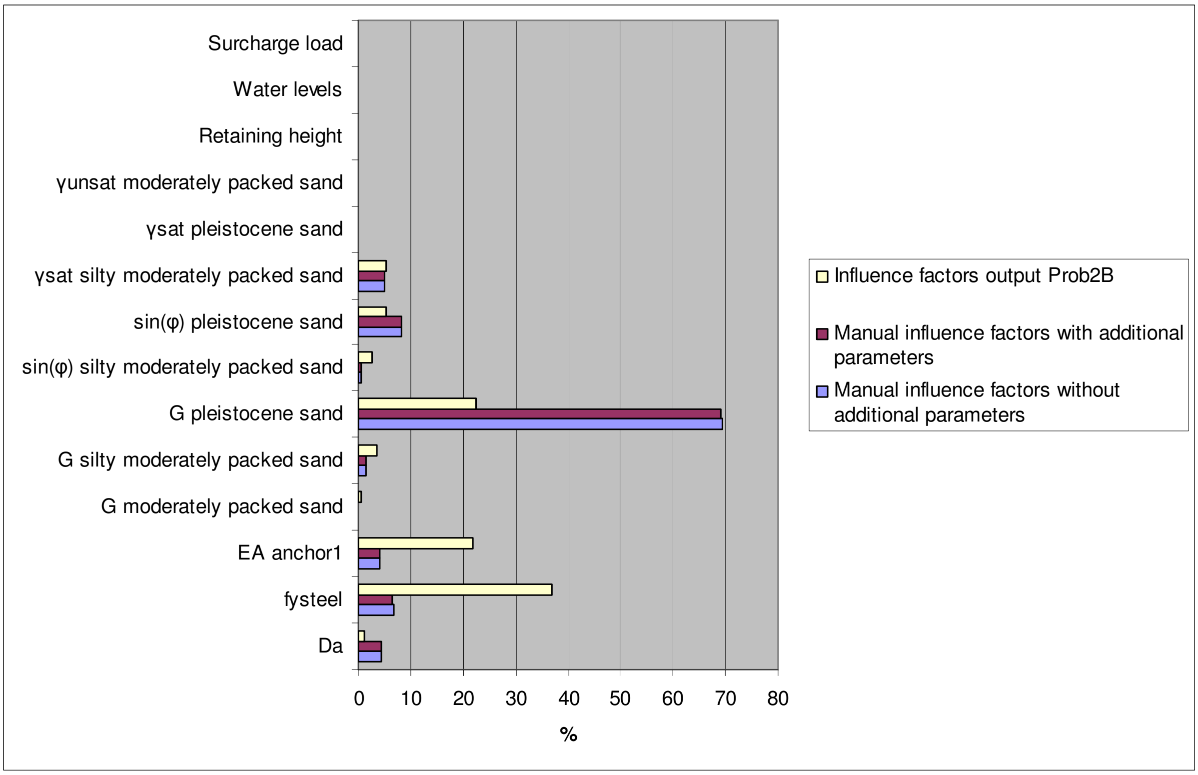

Figure M-1 Influence parameters on reliability beta = 4.40

M.1.2 Anchor 2 failure (ULS)

In the design point the three other parameters are varied manually in order to define α factors for these parameters as well. The results of the manual variation calculations are given in Table M-3.

Variation	$F_{anch2,stage4}$ [kN]
No variation (design point)	825
Retaining height +0.35 m	907
Water level inside +0.05 m outside -0.25 m	1065
Surcharge load +3 kN/m^2	842

Table M-3 Additional manual variations LS anchor 2

The α factors are all manually recalculated by using the FORM iteration before the final calculation. As this is not the final design point, the influence factors slightly differ from the final output of Prob2B as visualised in Figure M-2. The original influence factors are included to define partial safety factors as well as the manual obtained influence factors for the geometrical variations and governing surcharge load variations (Table M-4). These α factors are used to define partial safety factors for all parameters as presented in the main report.

X_i	α
$f_{y,steel}$	0.03
$EA_{anchor2}$	0.00
$E_{50,\text{silty moderately packed sand}}$	0.15
$G_{\text{moderately packed sand}}$	0.05
$G_{\text{silty moderately packed sand}}$	-0.30
$G_{\text{pleistocene sand}}$	-0.91
$\sin(\varphi)_{\text{moderately packed sand}}$	0.07

$\sin(\varphi)_{silty\ moderately\ packed\ sand}$	-0.04
$\sin(\varphi)_{pleistocene\ sand}$	0.14
$\gamma_{sat,silty\ moderately\ packed\ sand}$	-0.16
$\gamma_{sat,pleistocene\ sand}$	0.00
$\gamma_{unsat,moderately\ packed\ sand}$	0.03
Retaining height	0.01
Water level	0.02
Surcharge load	0.00

Table M-4 α factors including additional parameters

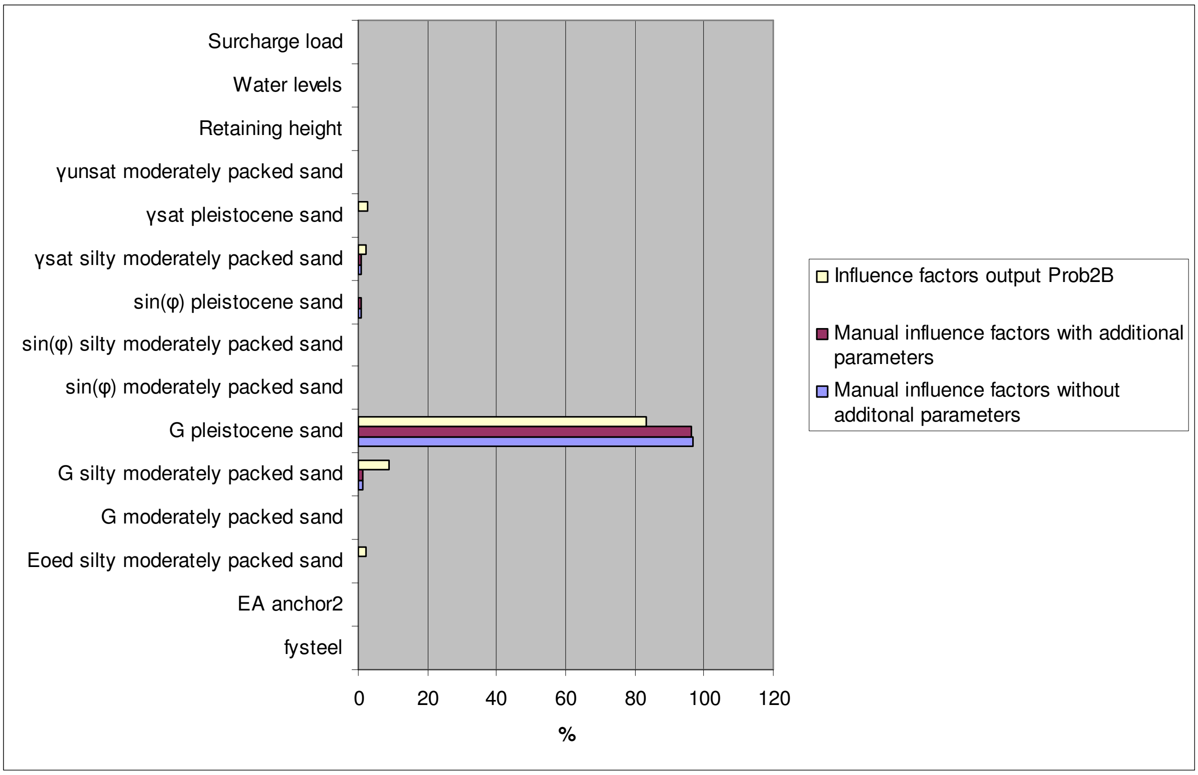

Figure M-2 Influence parameters on reliability beta = 2.99

M.1.3 Wall failure in bending (ULS)

In the design point the three other parameters are varied manually in order to define α factors for these parameters as well. The results of the manual variation calculations are given in Table M-5.

Variation	$\sigma_{steel,combi\text{-}wall}$[kN/m²]
No variation (design point)	337005
Retaining height +0.35 m	360110
Water level inside +0.05 m outside -0.25 m	370670
Surcharge load +3 kN/m²	338998

Table M-5 Additional manual variations LS wall

The α factors are all manually recalculated by using the FORM iteration before the final calculation. As this is not the final design point, the influence factors slightly differ from the final output of Prob2B as visualised in Figure M-3. The original influence factors are included to define partial safety factors as well as the manual obtained influence factors for the geometrical variations and governing surcharge load variations (Table M-6). These α factors are used to define partial safety factors for all parameters as presented in the main report.

X_i	α
$G_{silty\ moderately\ packed\ sand}$	-0.12
$G_{pleistocene\ sand}$	0.48
$\sin(\varphi)_{silty\ moderately\ packed\ sand}$	0.67
$\sin(\varphi)_{pleistocene\ sand}$	0.46
$\gamma_{sat,silty\ moderately\ packed\ sand}$	-0.30
Retaining height	0.09
Water level	0.13
Surcharge load	0.01

Table M-6 α factors including additional parameters

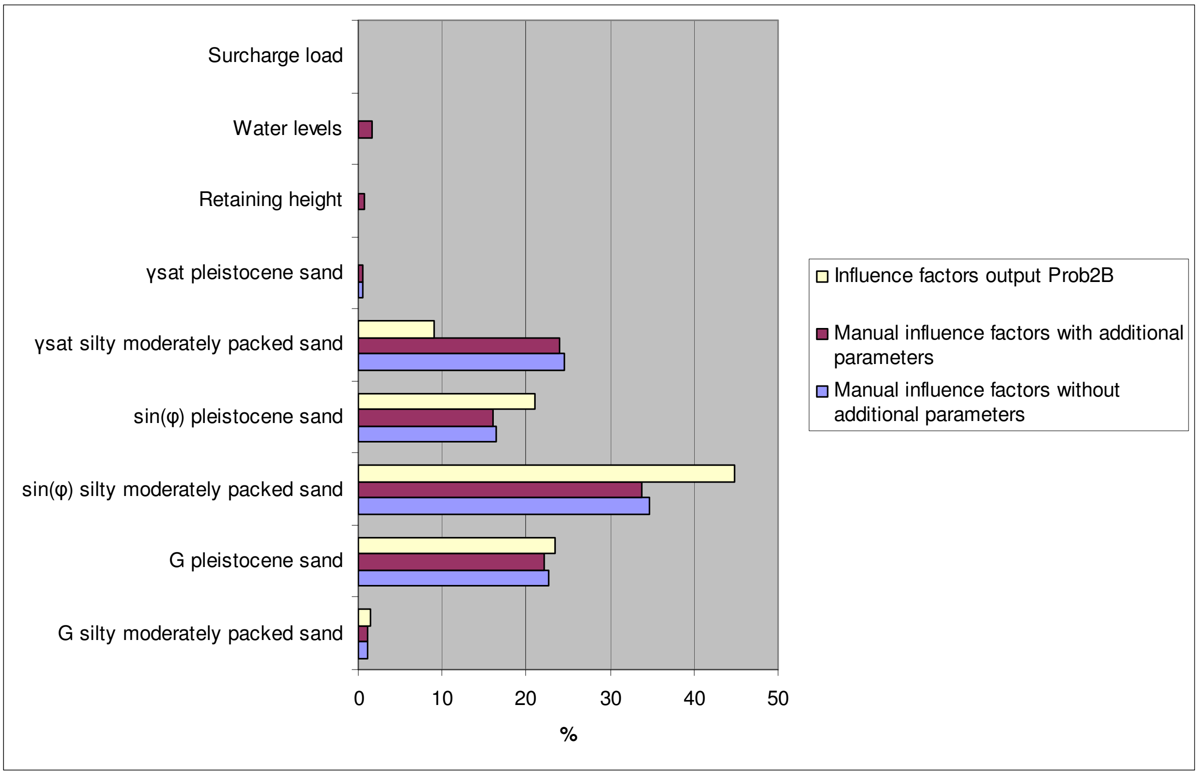

Figure M-3 Influence parameters on reliability beta = 2.65

M.1.4 Soil mechanical failure (ULS)

In the design point the three other parameters are varied manually in order to define α factors for these parameters as well.

The results of the manual variation calculations are given in Table M-7.

Variation	MSF [-]
No variation (design point)	1.107
Retaining height +0.35 m	1.089
Water level inside +0.05 m outside -0.25 m	1.112
Surcharge load +3 kN/m^2	1.085

Table M-7 Additional manual variations LS soil

The α factors are all manually recalculated by using the FORM iteration before the final calculation. As this is not the final design point, the influence factors slightly differ from the final output of Prob2B as visualised in Figure M-4. The original influence factors are included to define partial safety factors as well as the manual obtained influence factors for the geometrical variations and governing surcharge load variations (Table M-8). These α factors are used to define partial safety factors for all parameters as presented in the main report.

X_i	α
$E_{oed,pleistocene\ sand}$	0.48
$\sin(\varphi)_{pleistocene\ sand}$	0.80
$\gamma_{sat,pleistocene\ sand}$	-0.36
Retaining height	0.04
Water level	-0.01
Surcharge load	0.04

Table M-8 α factors including additional parameters

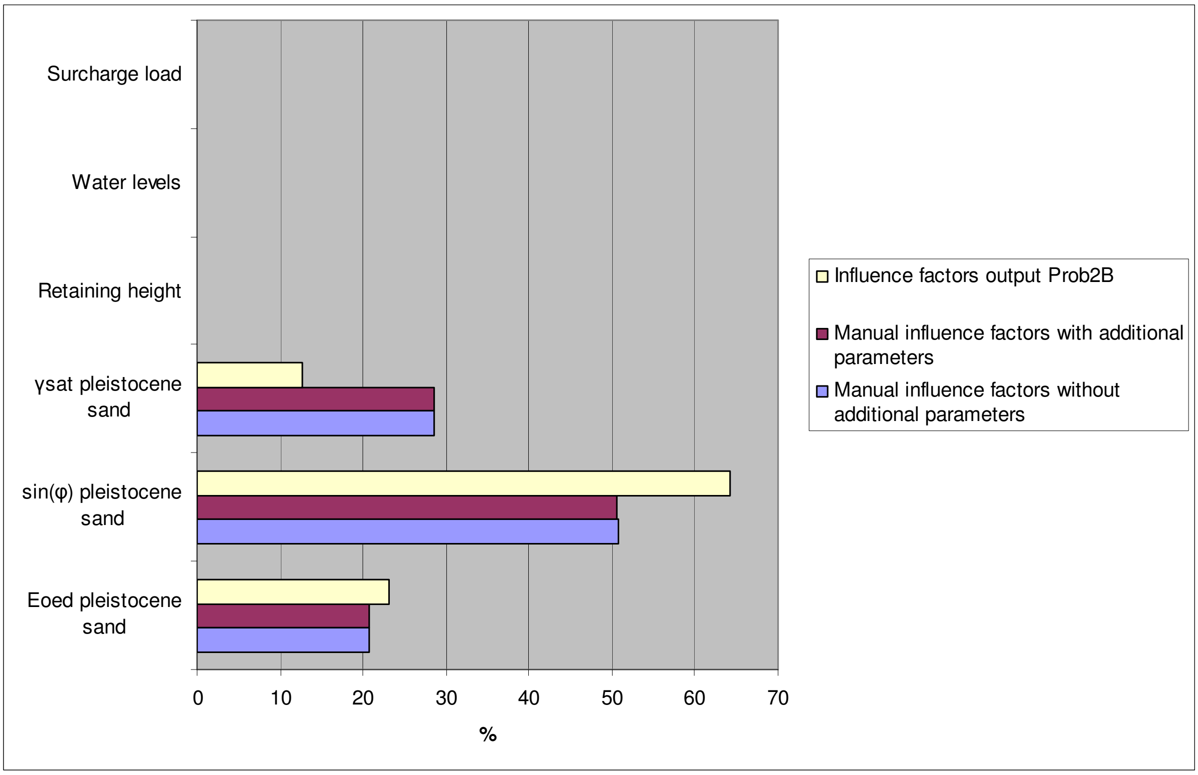

Figure M-4 Influence parameters on reliability beta = 2.78

M.1.5 Excessive deformations (SLS)

In the design point the three other parameters are varied manually in order to define α factors for these parameters as well.

The results of the manual variation calculations are given in Table M-9.

Variation	δ[m]
No variation (design point)	0.0457
Retaining height +0.35 m	0.0496
Water level inside +0.05 m outside -0.25 m	0.0518
Surcharge load +3 kN/m^2	0.0469

Table M-9 Additional manual variations LS deformations

The α factors are all manually recalculated by using the FORM iteration before the final calculation. As this is not the final design point, the influence factors slightly differ from the final output of Prob2B as visualised in Figure M-5. The original influence factors are included to define partial safety factors as well as the manual obtained influence factors for the geometrical variations and governing surcharge load variations (Table M-10). These α factors are used to define partial safety factors for all parameters as presented in the main report.

X_i	α
$G_{\text{silty moderately packed sand}}$	-0.19
$G_{\text{pleistocene sand}}$	0.42
$\sin(\varphi)_{\text{silty moderately packed sand}}$	0.65
$\sin(\varphi)_{\text{pleistocene sand}}$	0.48
$\gamma_{\text{sat,silty moderately packed sand}}$	-0.36
Retaining height	0.09
Water level	0.13
Surcharge load	0.03

Table M-10 α factors including additional parameters

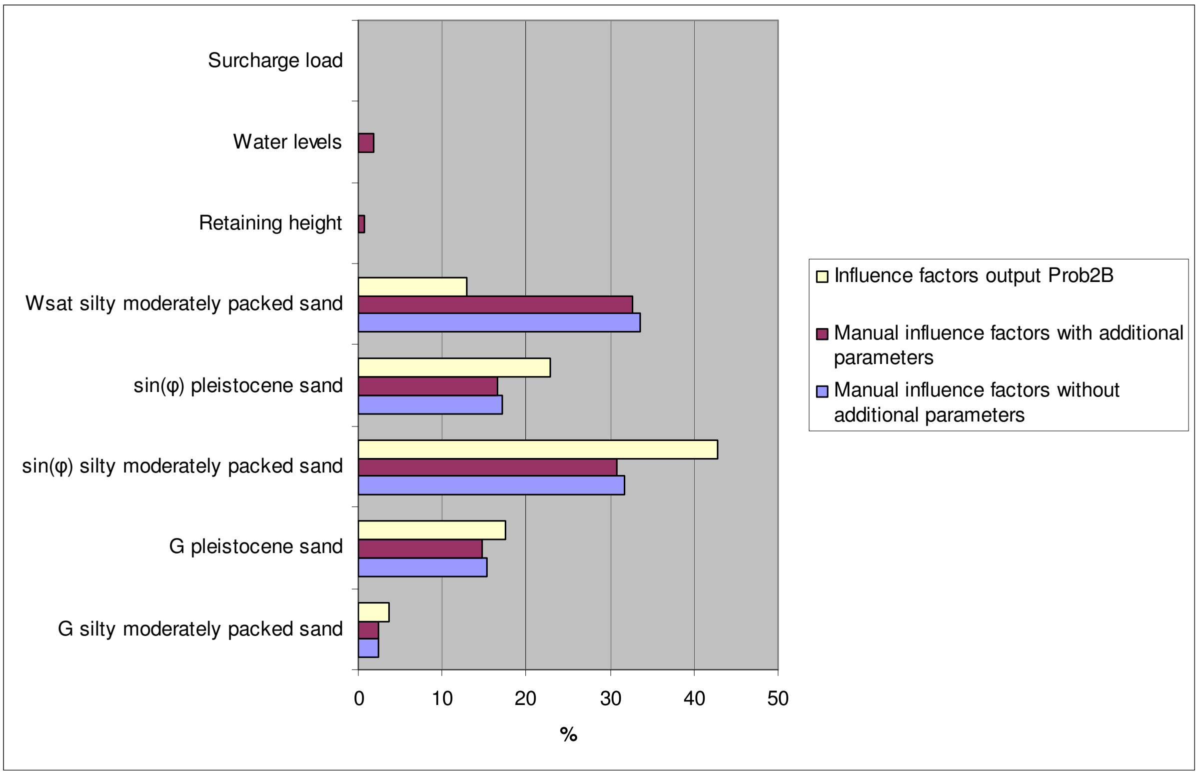

Figure M-5 Influence parameters on reliability beta = 2.44