University of Dundee GEOTECHNICAL Seminar

Probabilistic optimization design for Inclined Facing Embankment

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1 Optimal design based on failure prob

An optimal design modelling of urban flood inclined facing embankment with multi-objective, multi-constrain conditions was presented, considering dimensional requirement for many kinds of failure modes, such as sliding stability, seepage stability, settlement and overtopping, taking the overall present costs, such as the initial construction costs, maintenance and repair costs, as an object function, in order to obtain better benefit and safety degree.

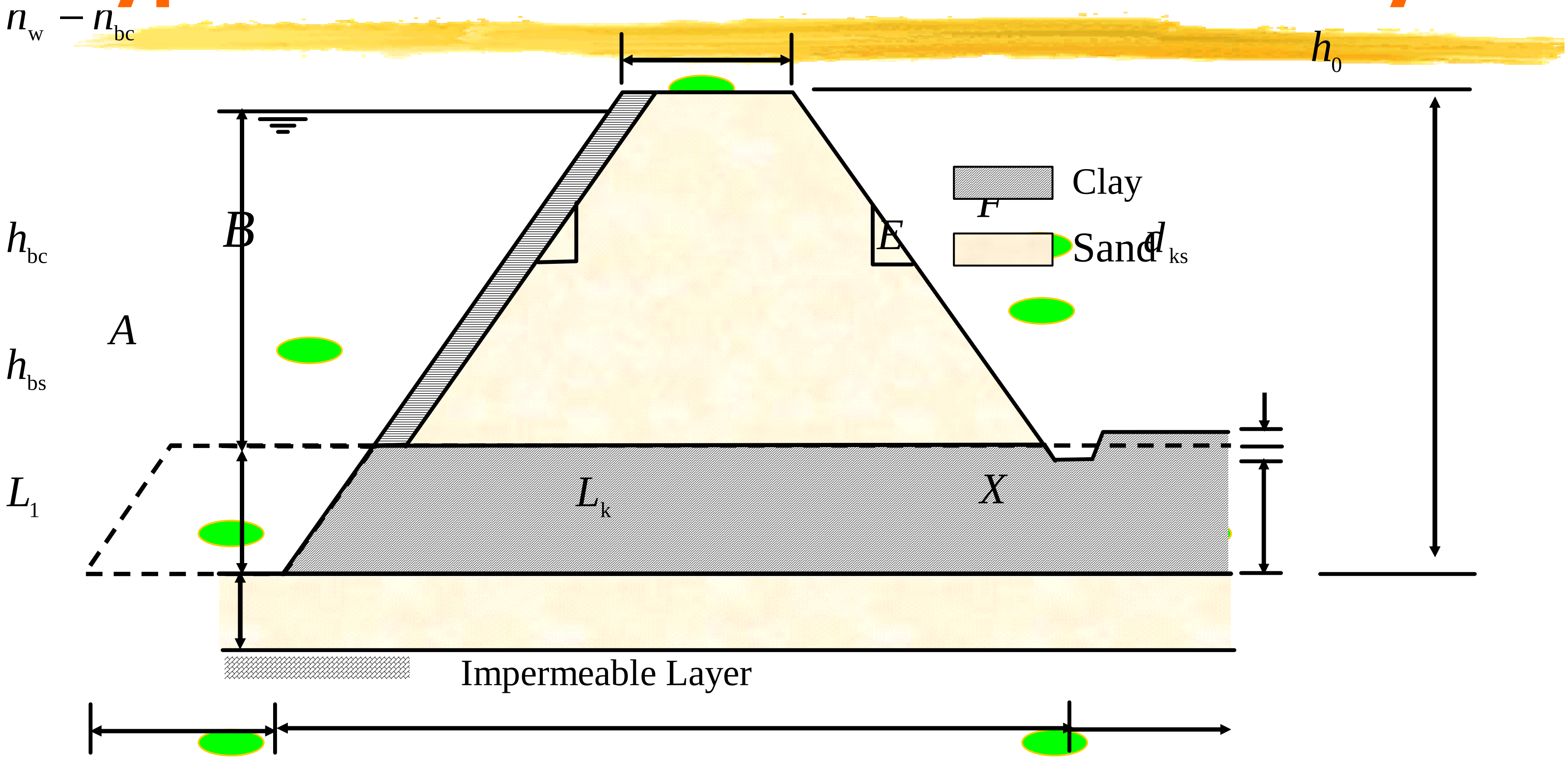
1 Optimal design based on failure prob

The total expected lifetime costs of the structure consisting of the investment and the expected value of the damage costs are minimised as a function of the design variables, and the geometric dimensions of the dike profile has been taken as the constraint condition.

The main advantage is that optimization techniques lead to optimal design and automation, i.e., the design variables are chosen by the optimization procedure and not by the engineer

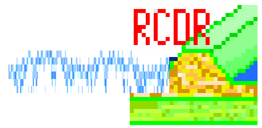
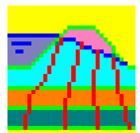
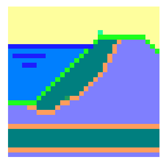
A decision model is presented enabling cost-optimal maintenance decisions to be determined while taking account of the (possibly large) uncertainties in soil parameters and flood water level or geometrics

1 Typical Dike Section Used This Study

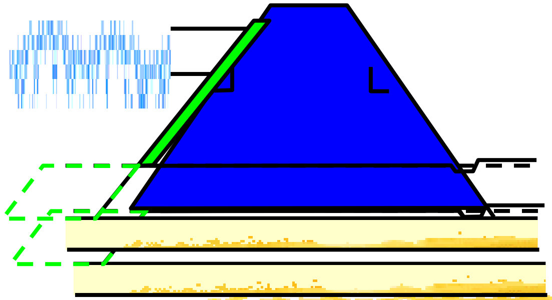


An idealized cross section with inclination facing on two-phase fluvial facies basement

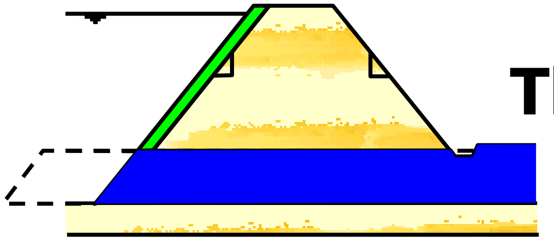
1 Limit State Equation of failure Modes

Failure mode	Limit state equation	Icon
Overtopping	$z_1 = h_0 - h_w - h_s - e$	
Piping	$z_2 = \gamma_{nk} d_{ks} - \gamma_w h_{ap} + \gamma_{sb} t_{sb}$	
Sliding	$z_3 = F_{SL} - 1 = M_r / M_o - 1$	

1 Parametric analysis (1)

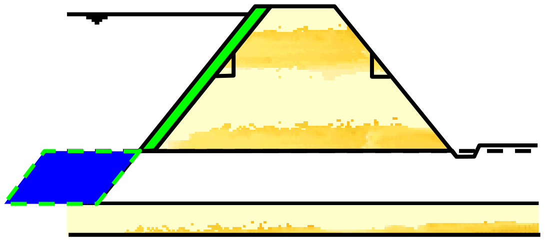


height of dike

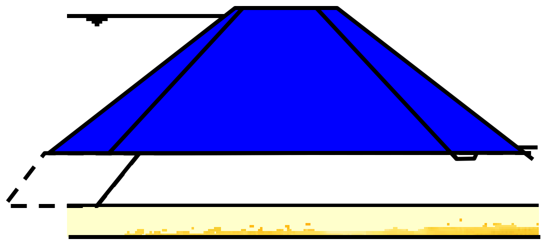


Thickness of clay stratum

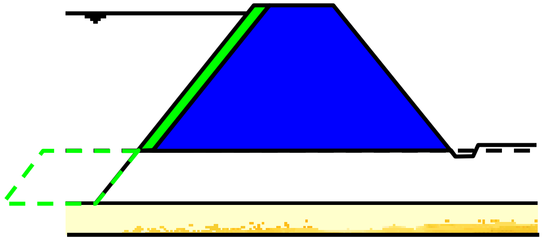
Width of foreland



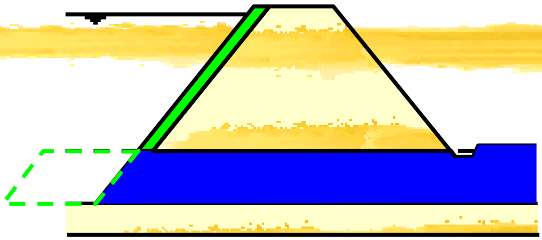
Slope ratio



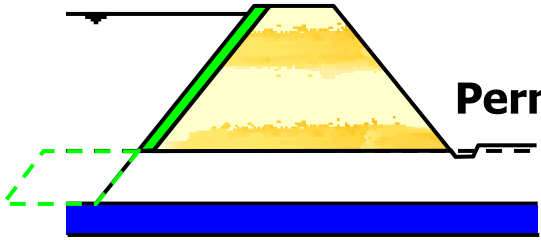
1 Parametric analysis (2)



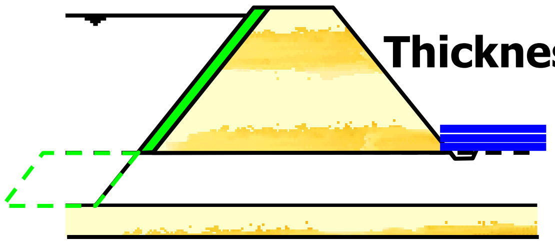
Crest width



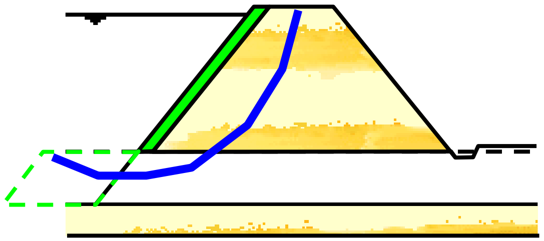
Permeability coefficient of clay



Permeability coefficient of sand



Thickness of piping-berm



Influence of slope ratio

2 Economic optimal design on overtopping

– crest height
- uncertainty in flood water level

2.1 Costs

4.2.1.1 Initial construction cost

$$IC_{\mathrm{O}} = (L_{\mathrm{d}}(w + mh_{\mathrm{f}})h_{\mathrm{f}})C_{\mathrm{F1}} + (L_{\mathrm{d}}h_{\mathrm{f}}\sqrt{1+m^2}t_{\mathrm{s}})C_{\mathrm{F2}}$$

4.2.1.2 Economic loss in protected area

$$L_{\mathrm{P}} = \left[A_{\mathrm{P}}\sum_{i=1}^{3}\alpha_i s_i c_i(d)\right]P_{\mathrm{fO}}$$

4.2.1.3 Maintenance costs

$$RC_{\mathrm{O}} = \int_0^t [RC \cdot p_{\mathrm{fF}}(t)/(1+i_{\mathrm{R}})^t]\mathrm{d}t$$

4.2.1.4 Residual value

2.2 Optimum modelling on Overtopping

4.2.2.1 Design variables

$$h_{\mathrm{f}}$$

4.2.2.2 Object function

$$\min f_{\mathrm{O}}(h_{\mathrm{f}}) = IC_{\mathrm{O}} + \sum_{t=0}^{N_{\mathrm{y}}} \frac{1}{(1+i_R)^t}(L_{\mathrm{P}} + RC_{\mathrm{O}}) - SV$$

4.2.2.3 Constraint Conditions

$$h_{\mathrm{fmin}} \quad h_{\mathrm{fmax}} \qquad\qquad P_{\mathrm{fO}} \le P_{\mathrm{fOmax}}$$

2.3 Crest height and object function

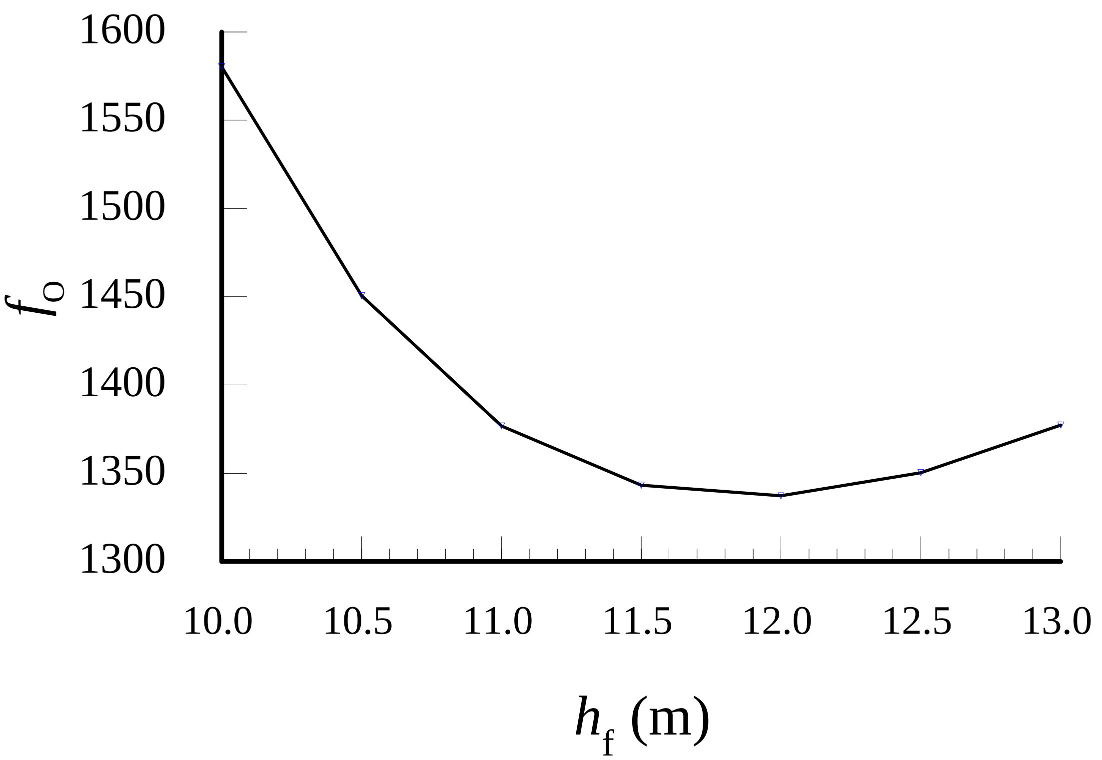


Fig 5.1 height with object function

2.3 Crest height and Failure Probability

The figure shows the probability of overtopping decrease with the increase of height.

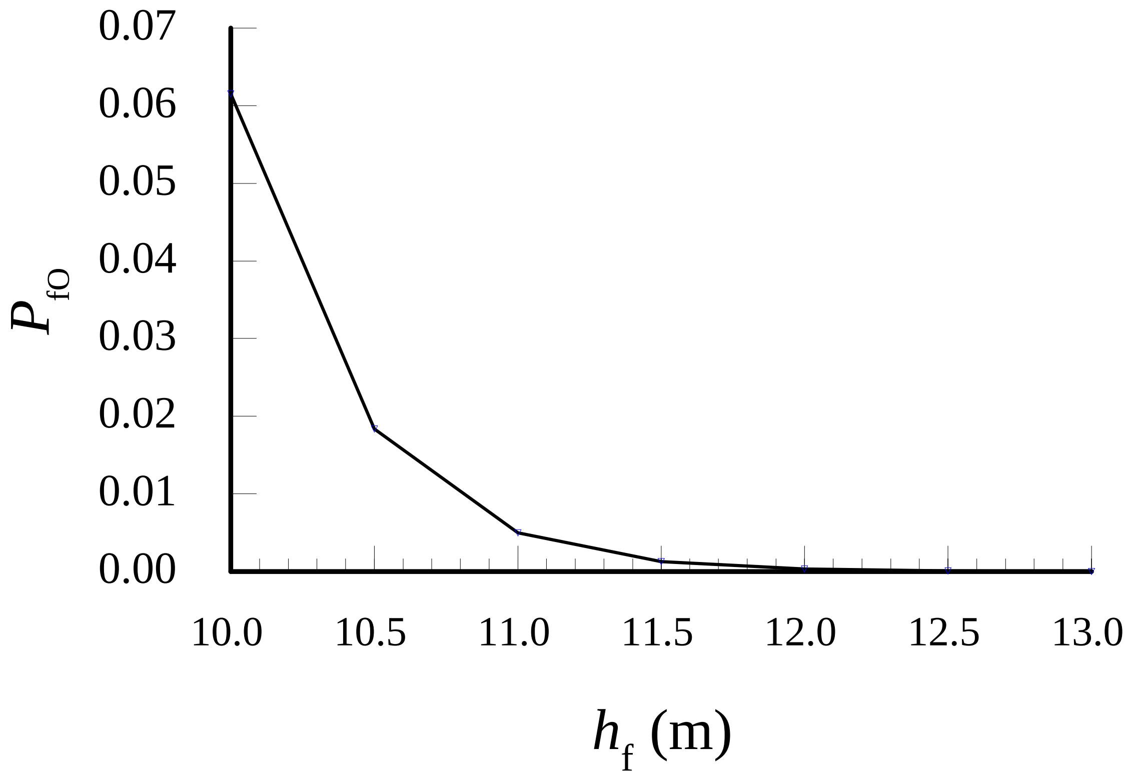


Fig 5.2 Height with probability of failure

2.3 Crest height and Reliability Index

Reliability index increase with the increasing of dike height. The reliability index is 3.295 when the crest height is 11.85m.

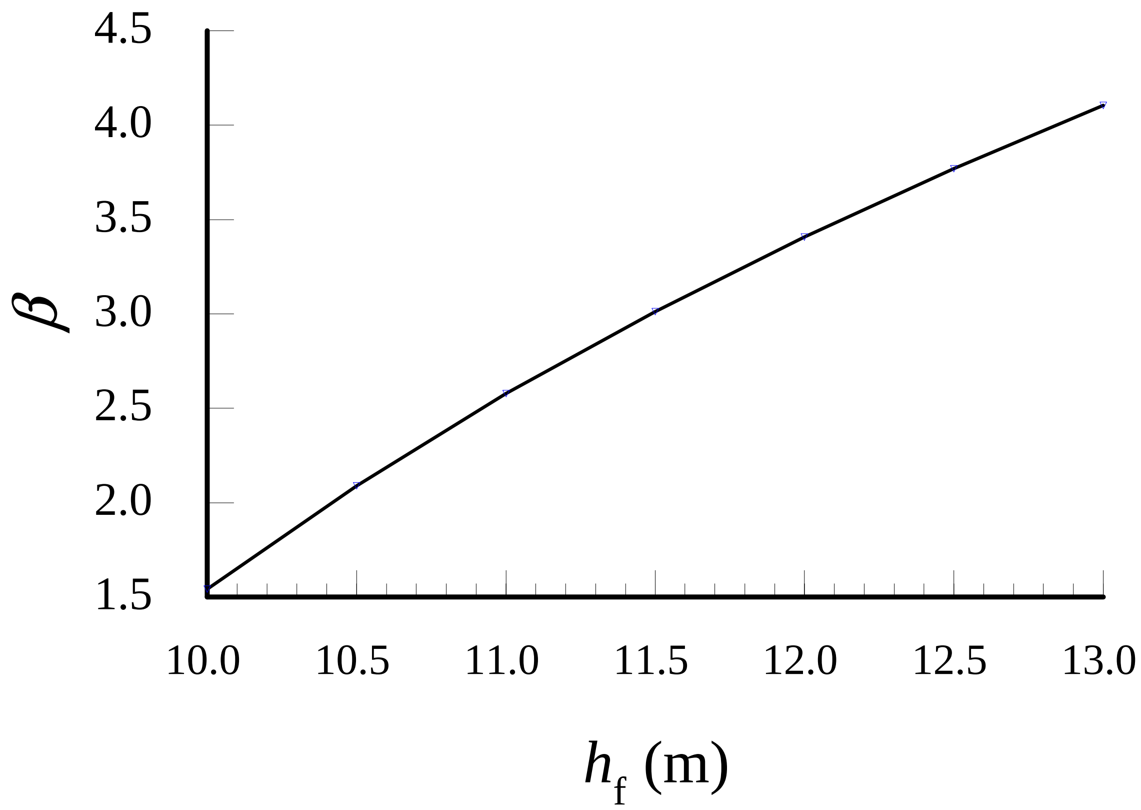


Fig 5.3 height with reliability index

2.3 Height with Initial construction costs

Almost linear increase relation

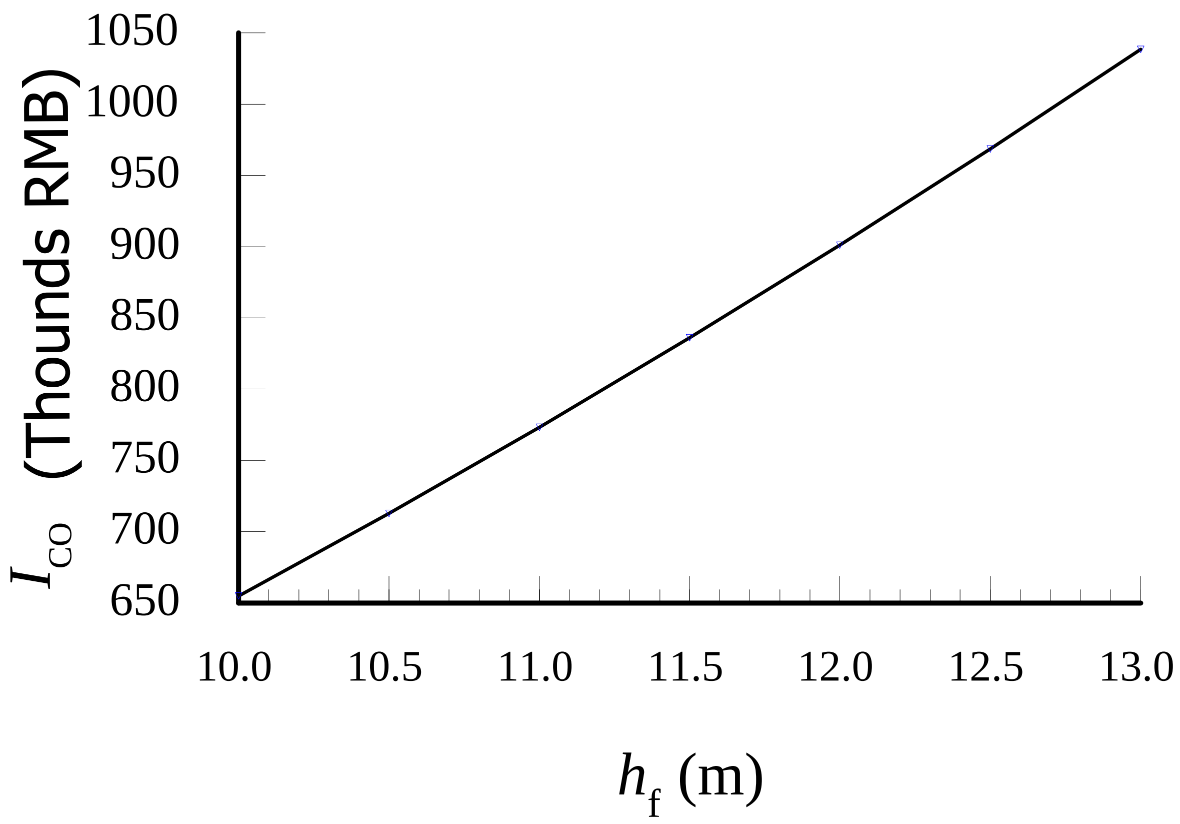


Fig 5.4 initial construction costs with crest height

2.3 Height with Maintenance costs

Owing to the probability of failure for overtopping reducing, the computed maintenance costs and economic losses of protected area decrease.

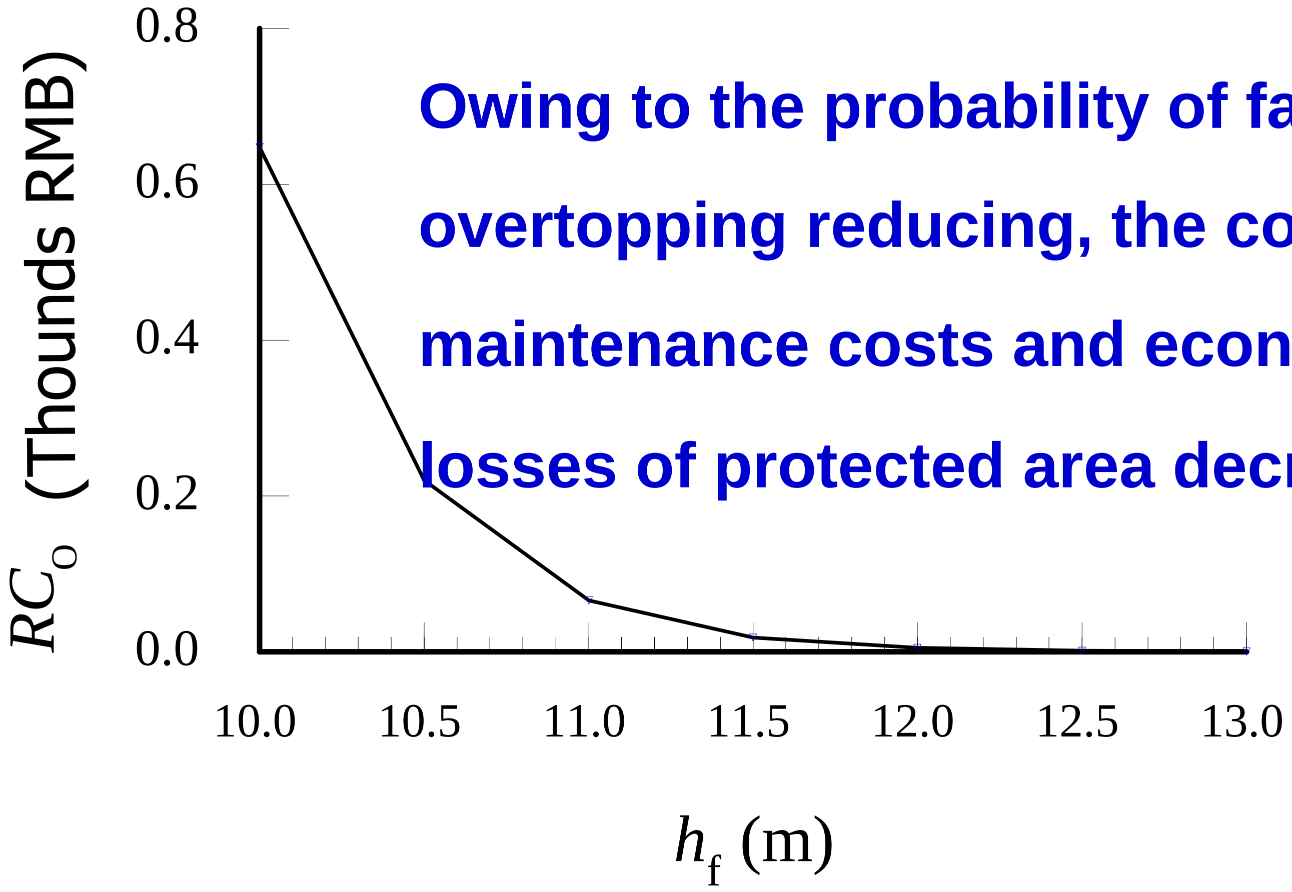


Fig 5.5 crest height with maintenance costs

2.3 Height with losses of protected area

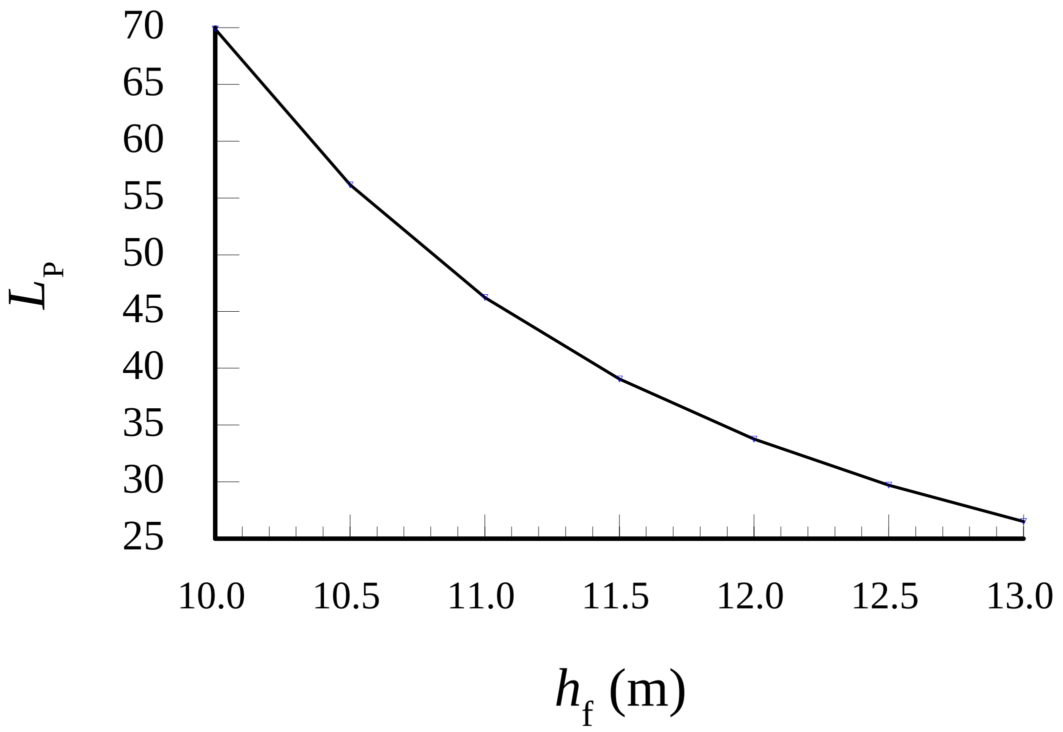
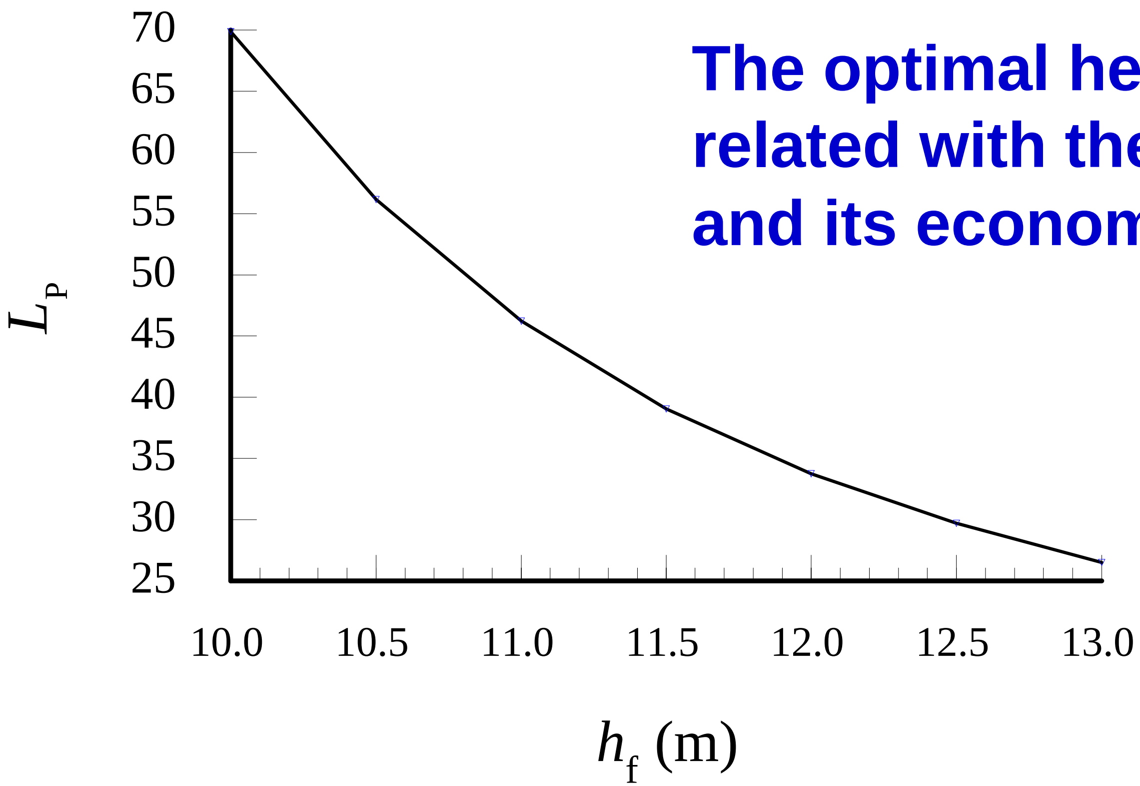


Fig. 5.6 crest height with losses of protected area

2.3 Protected area with optimal height



The optimal height are close related with the protected area and its economic conditions

Fig 5.7 Protected area with optimal height

2.3 Protected area and Object function

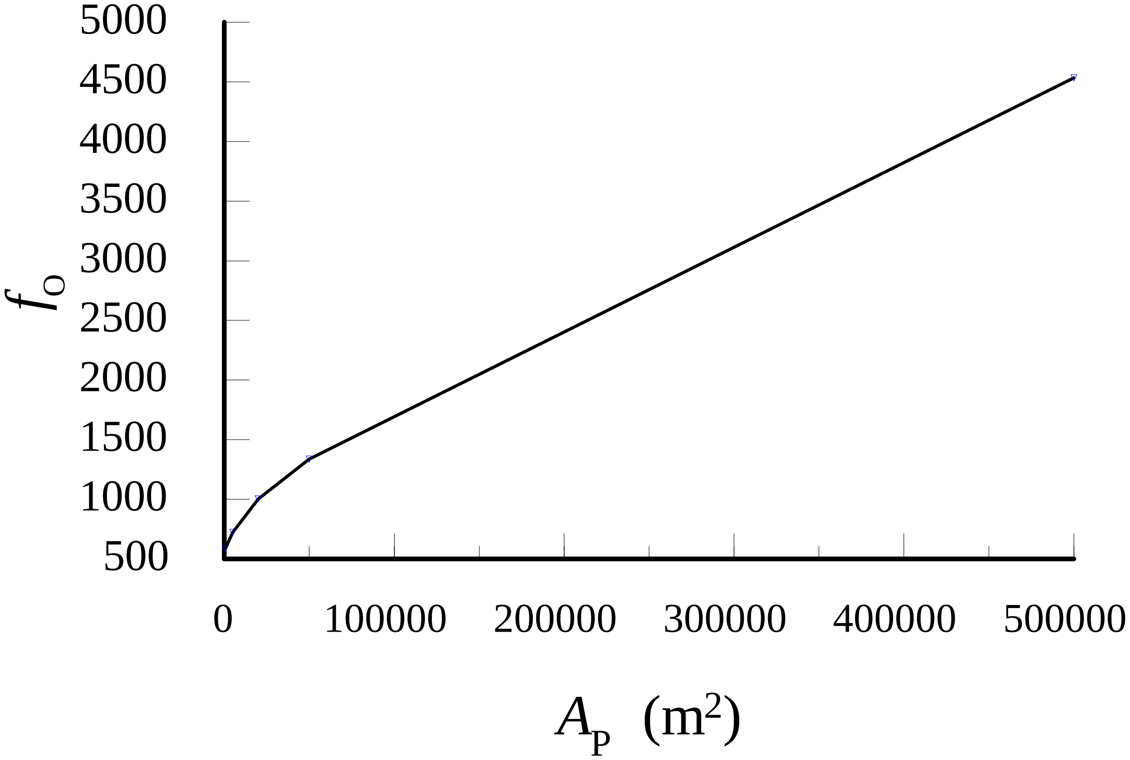
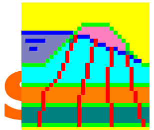


Fig 5.8 object function with various protected area

3 Economic optimal design on Piping

– Vars: width of foreland and berm
- Uncertainty in seepage Coefficients and Effective depth of the clay layer

3.1 Modelling of Piping Mechanism



safety factor

$$F_{\mathrm{CN}} = \Delta H_{\mathrm{strength}} / \Delta H_{\mathrm{loading}} = \frac{\gamma_{\mathrm{nk}} d_{\mathrm{ks}} + \gamma_{\mathrm{sb}} t_{\mathrm{sb}}}{\gamma_{\mathrm{w}} h_{\mathrm{ap}}}$$

residual head of weak permeable stratum

$$h_{\mathrm{ap}} = \frac{h_{\mathrm{w}}}{1 + A * L_{\mathrm{k}} + \tanh A * L_{1}} e^{-AX}$$

a **coefficient**

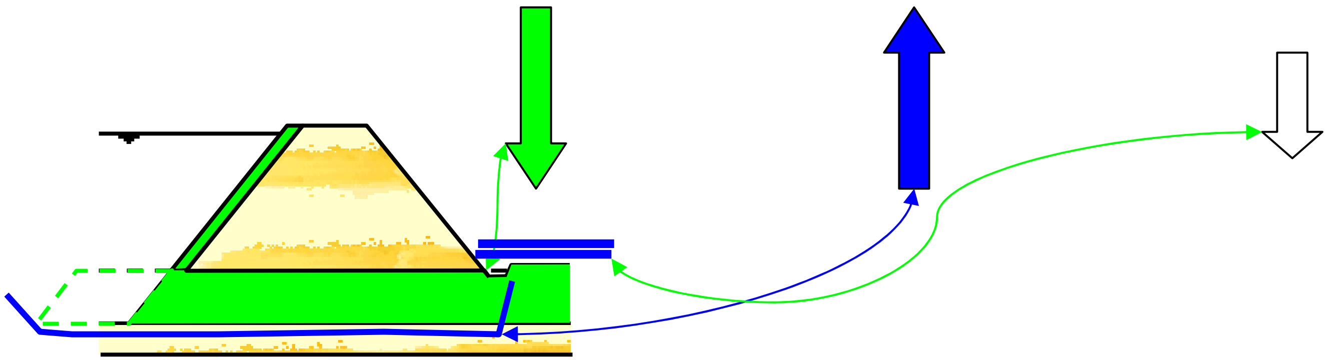
$$A = \sqrt{\frac{k_{\mathrm{c}}}{k_{\mathrm{s}} h_{\mathrm{bc}} h_{\mathrm{bs}}}}$$

effective seepage path length

$$L_{\mathrm{k}} = 2 * m * h + w + m * h_{\mathrm{bc}}$$

3.1 Modelling of piping mechanism

$$z_2 = \gamma_{nk} d_{ks} - \gamma_w h_{ap} + \gamma_{sb} t_{sb}$$



Clay layer | **Residual water head** | **Piping-berm**

3.2 Cost model of Piping

Initial construction costs

$$IC_{\mathrm{P}} = L_d \cdot \left(L_1 \cdot t_{\mathrm{sb1}} \cdot C_{\mathrm{P2}} + L_2 \cdot t_{\mathrm{sb2}} \cdot C_{\mathrm{P3}}\right)$$

Maintenance cost of the foreland and piping berm

$$MC_{\mathrm{P}} = L_{\mathrm{fp}} \cdot \left(L_1 \cdot t_{\mathrm{sb1}} \cdot C_{\mathrm{P2}} + L_2 \cdot t_{\mathrm{sb2}} \cdot C_{\mathrm{P3}}\right) \cdot \frac{P_{\mathrm{fP}}}{N_{\mathrm{y}}} \cdot upw$$

3.2 Optimum modelling of Piping

4.2.2.1 Design variables

$L_1 \quad L_2$

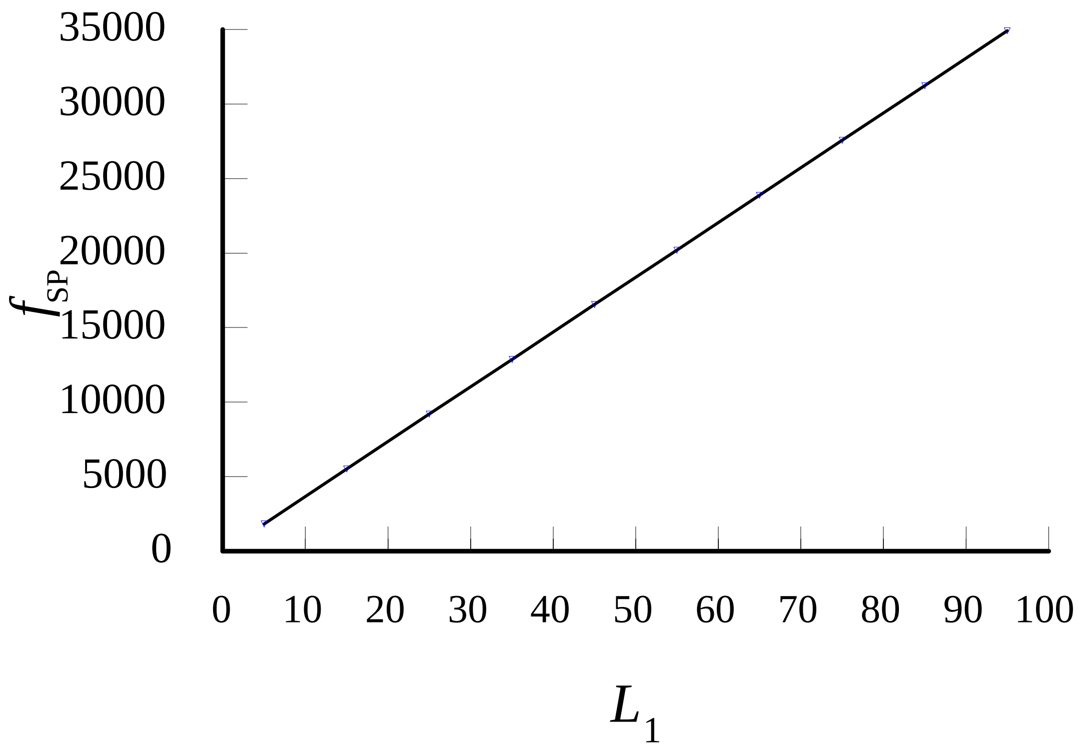
4.2.2.2 Object function

$$\min\ f_{\mathrm{P}}(L_1, L_2) = IC_{\mathrm{P}} + \sum_{t=0}^{N_{\mathrm{y}}} \frac{1}{(1+i_R)^t} MC_{\mathrm{P}}$$

4.2.2.3 Constraint Conditions

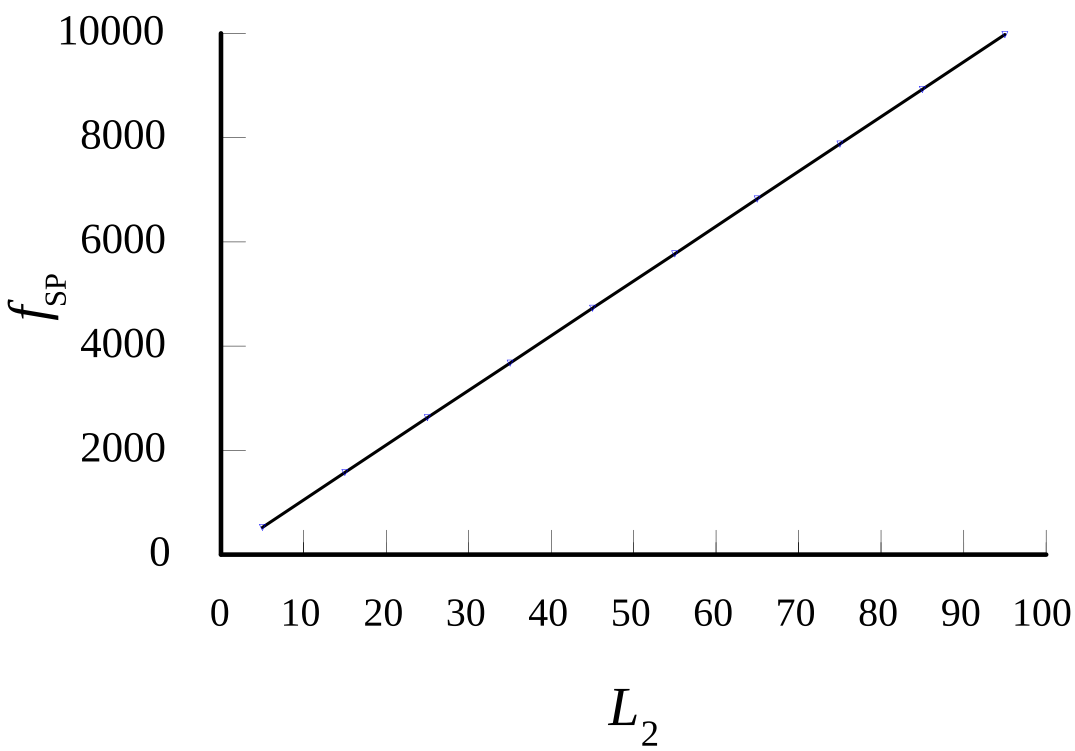
$L_1 \le L_{1\max} \qquad L_2 \le L_{2\max}$

3.3 Foreland width and object function



Width of foreland with its object function

3.3 Piping berm width and object function



Width of piping berm with its object function

4 Optimum object reliability index of slope stability

– Var: Slope ratio

- Uncertainty in Soil strength parameters

4.1 cost modelling of sliding

Initial construction costs

$$IC_{\mathrm{O}} = (L_{\mathrm{d}}(w + mh_{\mathrm{f}})h_{\mathrm{f}})C_{\mathrm{F1}} + (L_{\mathrm{d}}h_{\mathrm{f}}\sqrt{1+m^2}t_{\mathrm{s}})C_{\mathrm{F2}}$$

Maintenance cost of slope and repairing cost

$$MC_{\mathrm{F}} = upw \cdot C_{\mathrm{F3}}$$

$$RC_{\mathrm{F}} = CR \cdot \frac{P_{\mathrm{fF}}}{N_{\mathrm{y}}} \cdot upw$$

$$CR = L_{\mathrm{sf}}h_{\mathrm{R}}B_{\mathrm{R}}CC_{\mathrm{R}} + L_{\mathrm{sf}}h_{\mathrm{f}}\sqrt{1+m^2}t_{\mathrm{s}} \cdot C_{\mathrm{F2}} + 0.5L_{\mathrm{sf}}(w + mh_{\mathrm{f}})h_{\mathrm{f}}) \cdot C_{\mathrm{F1}}$$

4.2 Optimum modelling

4.2.2.1 Design variables

m

4.2.2.2 Object function

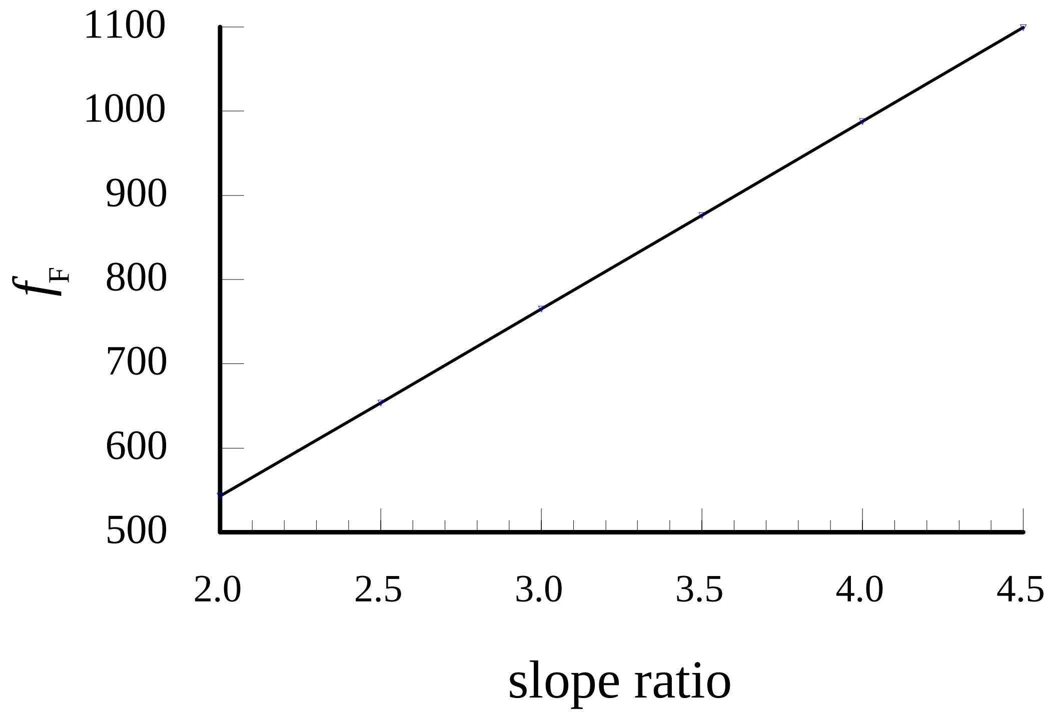
$$\min f_{\mathrm{F}}(m) = IC_{\mathrm{F}} + \sum_{t=0}^{N_{\mathrm{y}}} \frac{1}{(1+i_R)^t}(MC_{\mathrm{F}} + RC_{\mathrm{F}}) - \frac{1}{\left(1+i_{\mathrm{R}}\right)^{N_{\mathrm{y}}}} SV$$

4.2.2.3 Constraint Conditions

$$m_{\min} \leq m \leq m_{\max}$$

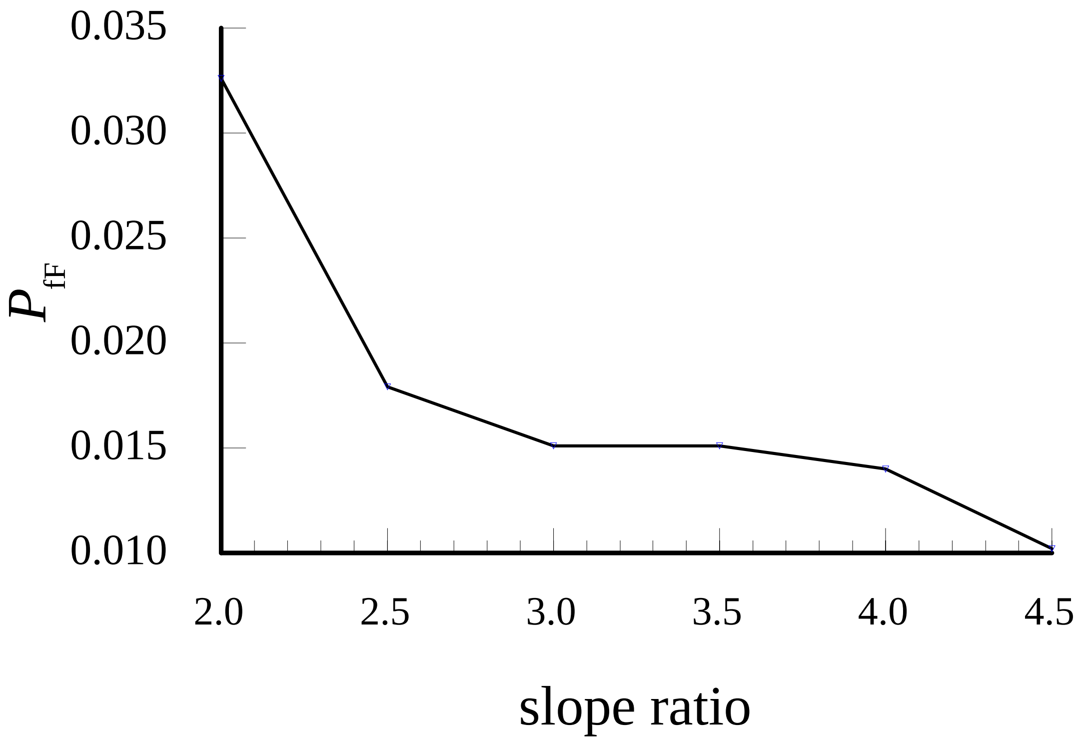
$$P_{\mathrm{fF}} \leq P_{\mathrm{fFmax}}$$

4.3 Slope ratio and its object function

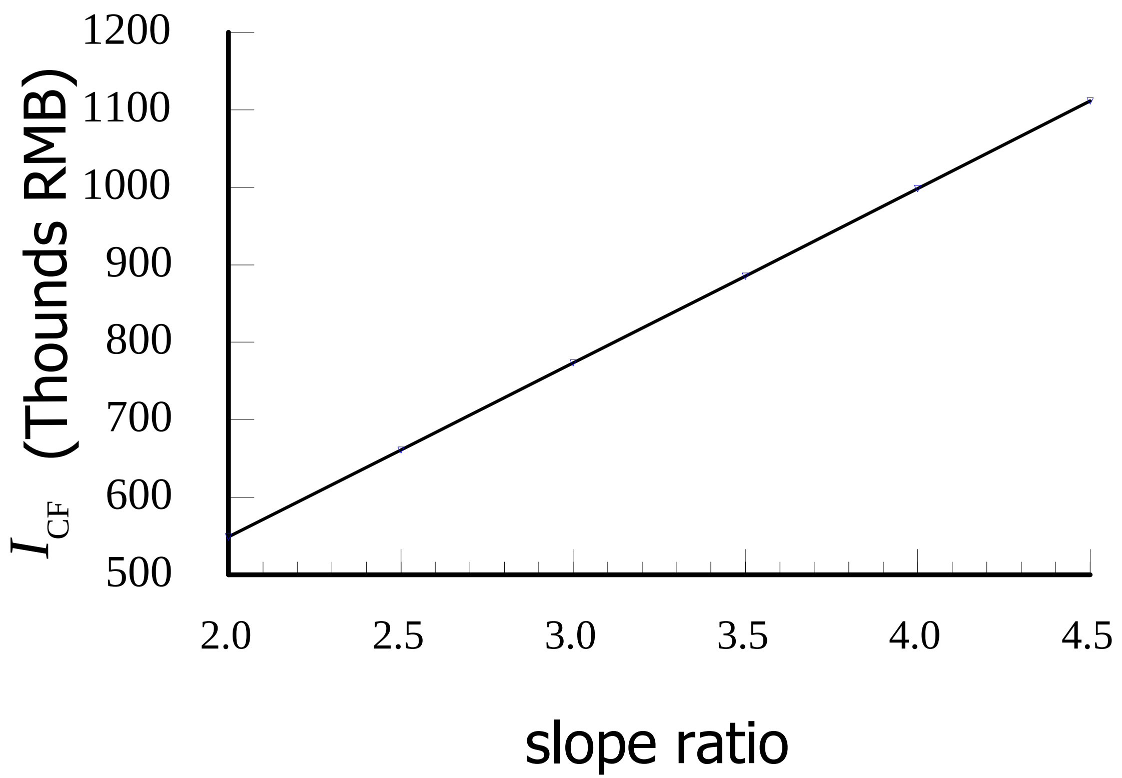


Slope ratio and its object function

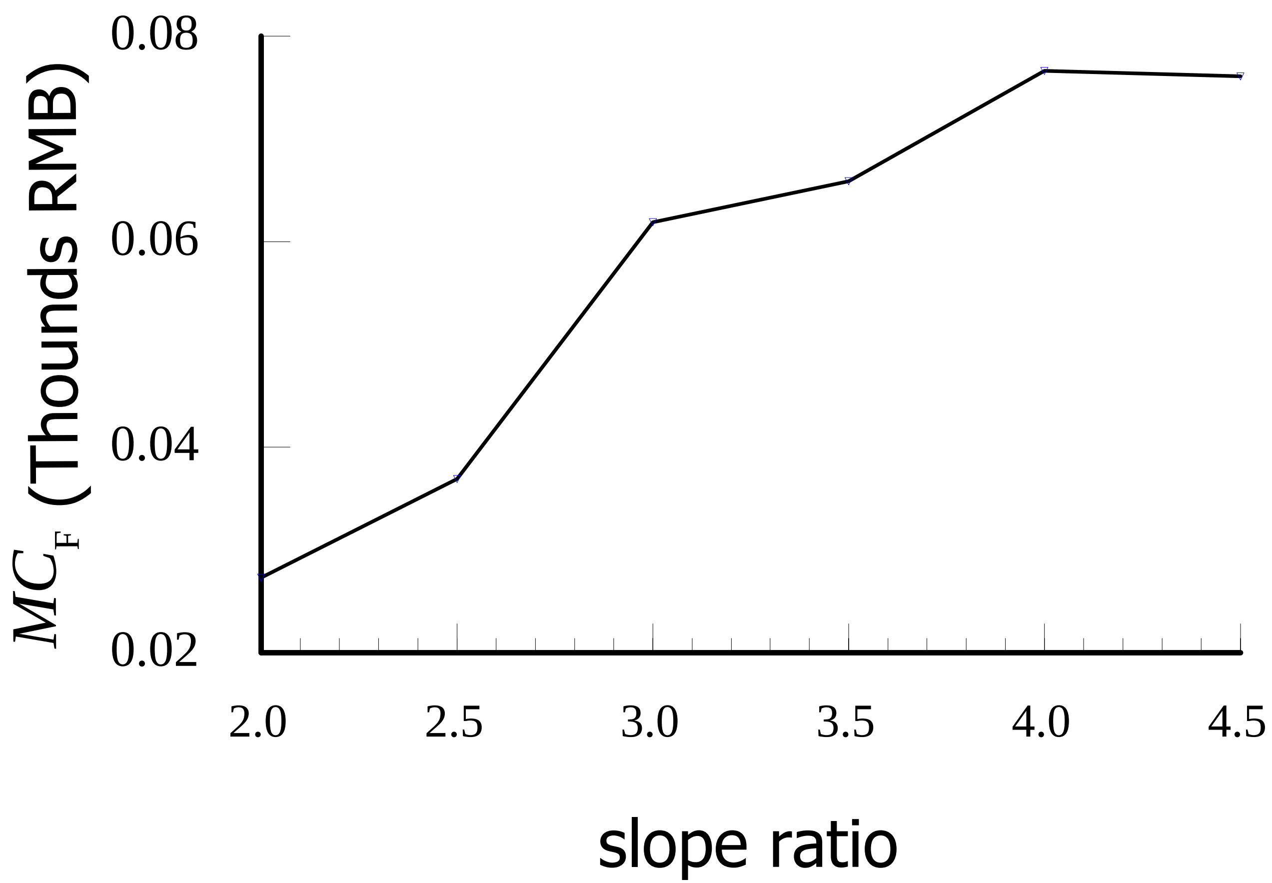
4.3 Slope ratio and probability of sliding



4.3 Slope ratio and Initial construction costs



4.3 Slope ratio and maintenance cost



5 Diagram of probabilistic design Process

height ← flood water height and wind wave

↓

thickness of clay layer ← characteristics of piping

↓

slope ratio/width cross crest/ foreland/piping-berm/fill ← characteristics of piping

↓

strength characteristics ← slope stability

↓

Suggestion of Strengthenment and Rebuilding ← Traditional Methods

5 Optimal solving method

- The Complex Method (used here)
- **First presented by Box and later improved by Guin, can be applied to mixed continues and discrete variable problems**

- Random Search
- Tabu Search
- Hybrid Methods

5 Multi-objective optimal results

⌘**Taking the crest height and slope ratio and width of piping berm as design variables in multi failure modes, the individual constraint condition in various failure modes as the overall constraint conditions, and the overall present costs in various failure modes as object function**

Table 7.4 Results of multi-object functions with multi constraint conditions

Object function (RMB)			Reliability index			Design Variables			Mode
Overtopping	Sliding	Piping	Overtopping	Sliding	Piping	H_f (m)	m	L_2 (m)	
1341.99	603.11	1890.12	1.90	2.09	2.87	10.5	2.5	17.78	Multi
1376.66	764.91	525.06	2.57	2.16	2.71	11.85	3.0	5	Individual

6 Conclusions (1)

For overtopping, the initial construction cost increase and the inundated loss and maintenance cost decrease with the increase of dike height. The minimum object function can be gained at the dike height of 11.85m, i.e. 1.336 million RMB, and the probability is 0.0005.

For the sliding and piping, the overall costs will increase with the increase of the design variables. The reason is that the economic loss of the protected area will not counted in these cases. Their object function will depend on the initial construction costs, because the maintenance cost is lower with the less probability of failure.

6 Conclusions (2)

There is a difference of design variables between the results obtained in the individual mode and the ones gained in overall failure modes. The optimum crest height is 11.85m for the individual mode and 10.5m for overall mode. The importance and potential failure modes of different structural components should be considered.

The Complex method can solve the multivariable constrained multi-objective optimization problem

谢谢各位同仁

谢谢光临

Thanks

谢谢光临

Cooperation

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