How To Combat Floods?

Passive -> Active

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Research on Probabilistic Design Method of Flood Defenses

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- Main failure modes on dike or levee
- Limit state equation
- Monte Carlo method
- Case study---sensitivity analysis
  (1)Overtoping;(2)Piping;(3)Sliding Stability
- Some conclusions

This is a Challenging Topic

- According to the existing code of dike design, the designing method of dike is safety margin method based on limit equilibrium analysis, which can't offer reliability index/failure of probability for the practical engineering.
- But for the probabilistic design method, the stochastic character of the geometric and strength parameters can be taken into account, so various designing indexes are adopted according to the importance of different components of dike in order to decrease engineering cost.

Conventional → Rational Means

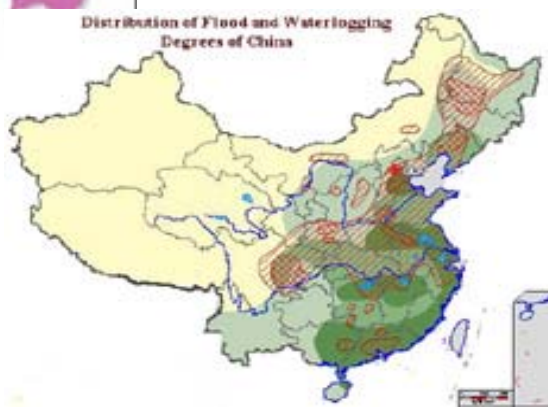
This is a Challenging Topic

- Recent years, drastic floods have occurred in some large river basins. After flood, dikes must be heightened and widened. Therefore, it is important to study the influence of the variation of Geometry and Geotechnical parameters of flood defense on structural safety or reliability index for design, construction and safety management of dikes.
- In the Netherlands/Australia/USA/Canada, some methods of probabilistic design and safety assessment of embankment and revetment engineering have been discussed by some design guides and handbooks. But in China, further study should be carried out.

The conventional method is valid in China?/!

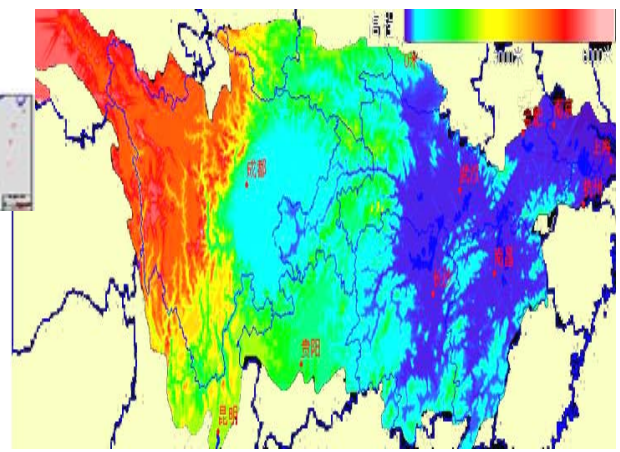
Position of This Case Study

world



China

Yangtze River



Position of This Case Study

Yangtze River

Anqing Dike Ring

How To Combat Floods?

[1998BBC] The decisive battle to beat the flood has begun, and danger may appear at any time, especially around the inland lakes, above the warning level.

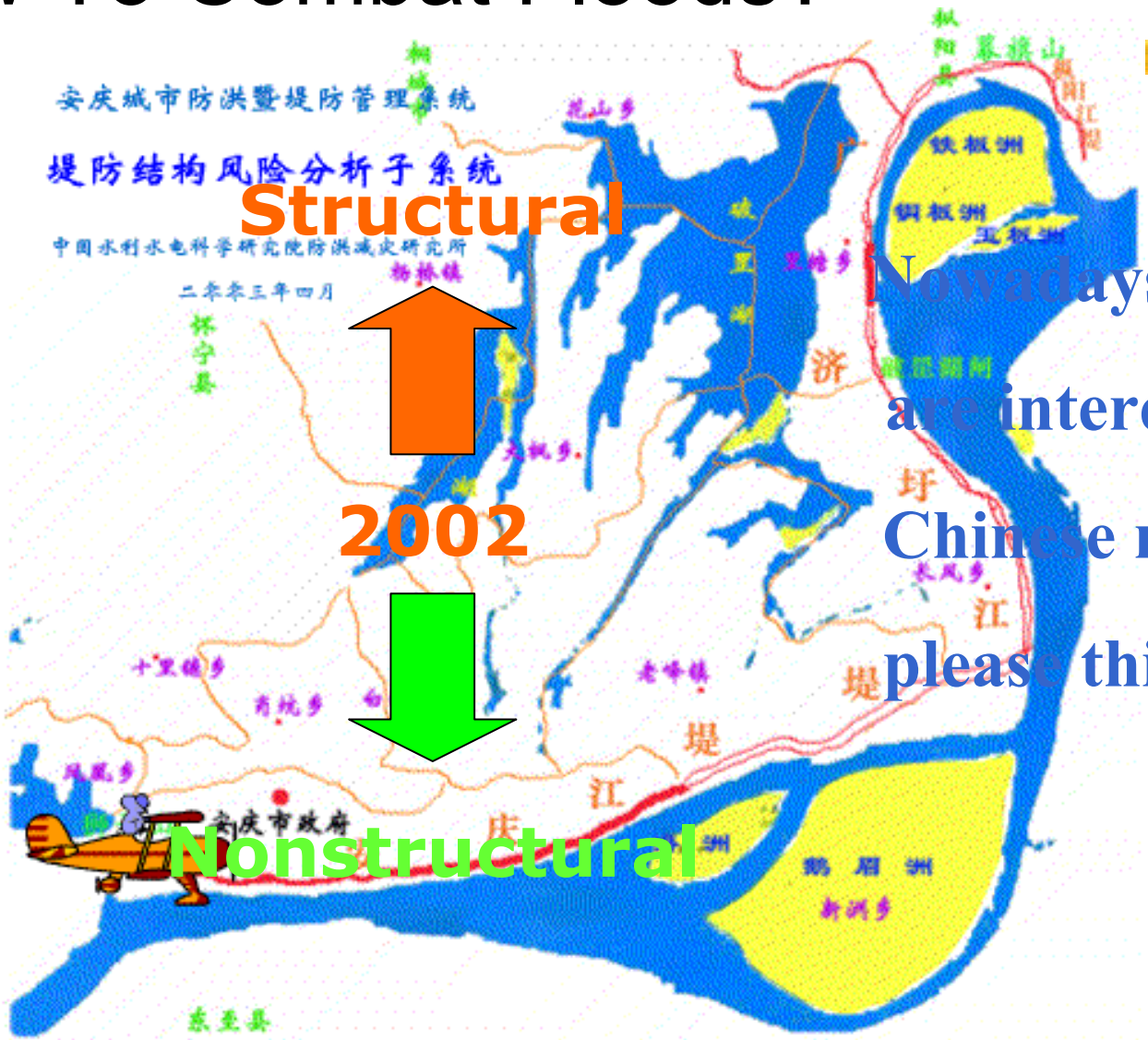
Some 3,500 local people are now defending the dikes while soldiers and armed police officers are on standby for rescue work.

How To Combat Floods?

For Yangtze river alone, some 29 billion yuan (EURO 3.4 billion) was earmarked during the 1998-2002 period to strengthen 3000 kilometer-long major levees shielding vast area along the river's middle and lower reaches.

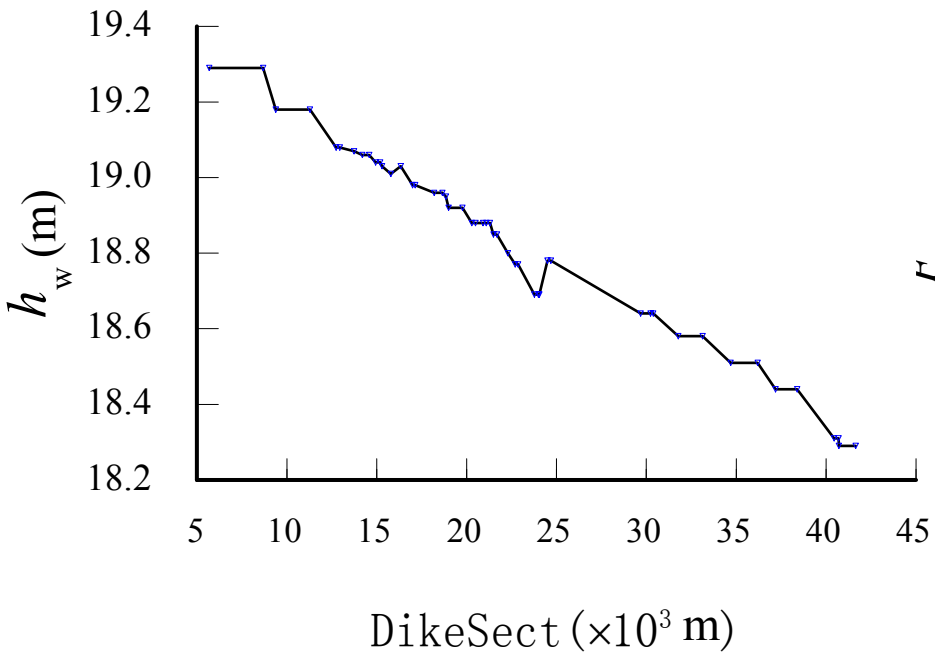
In this case, Wang (Minister of water resources) said confidently that " in the next 50 to 100 years, there will be no need for China to launch another large-scale reinforcement of the levees"

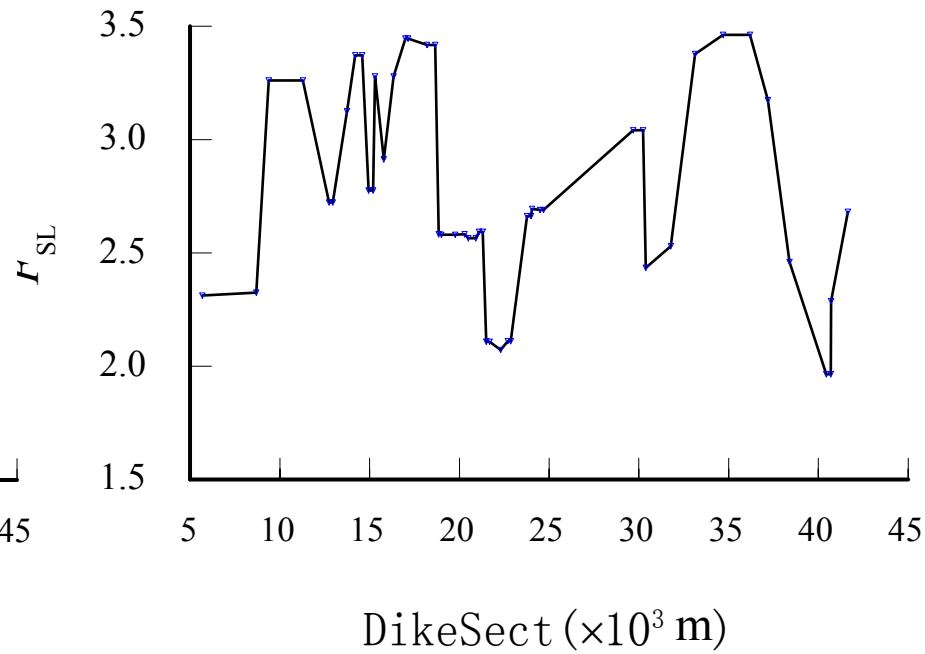
How To Combat Floods?



The process starts with dividing the flood defence system into more detailed subsections

For Whole Dike Section

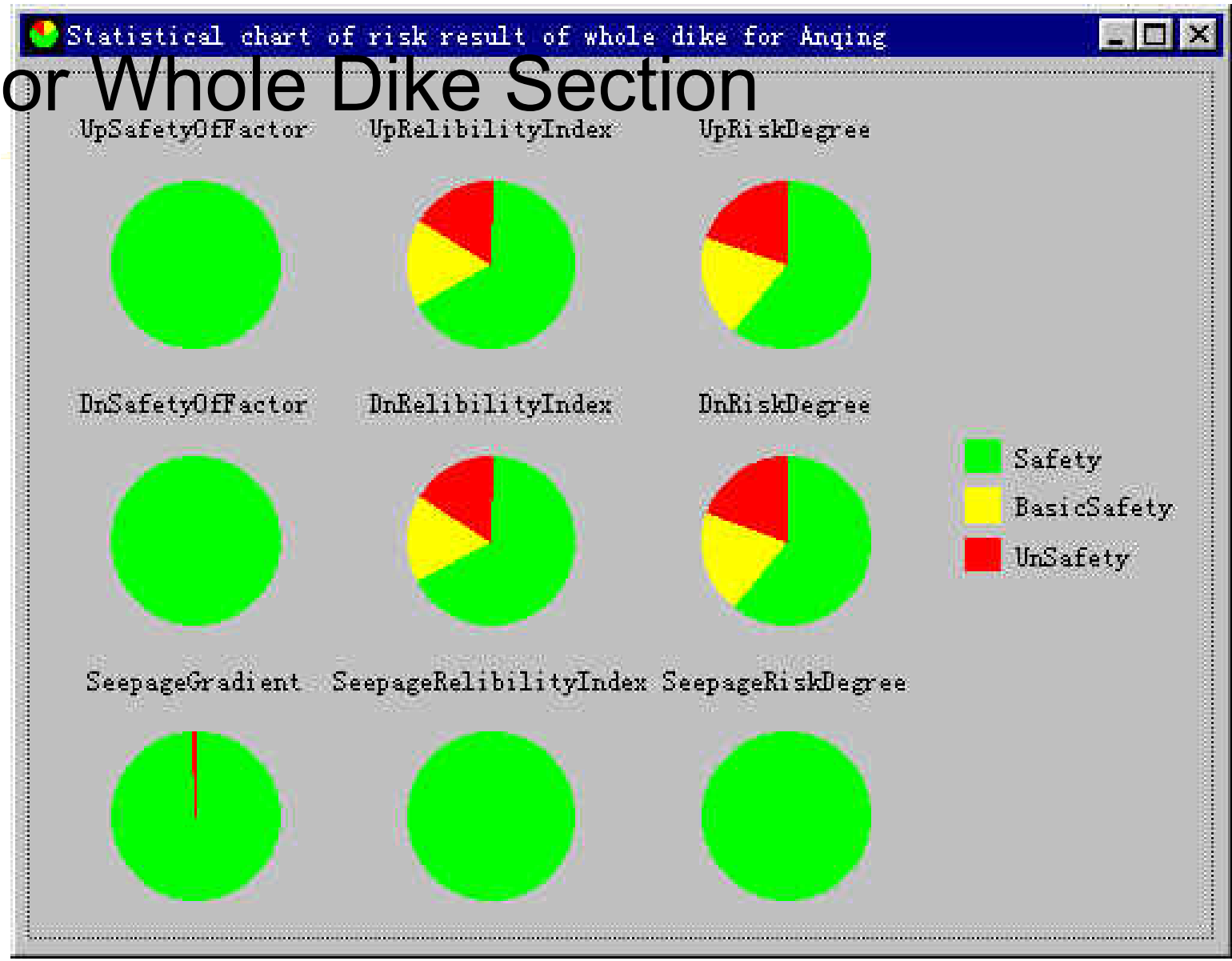




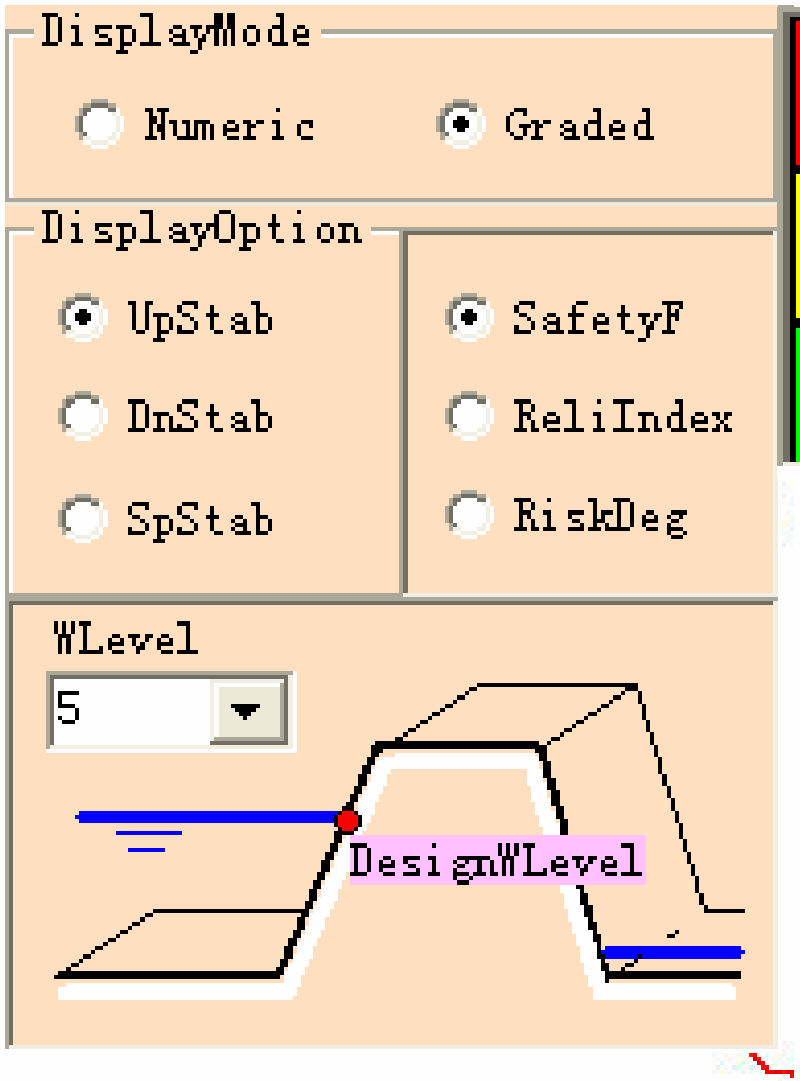
Distribution of Design Water level for whole dike section

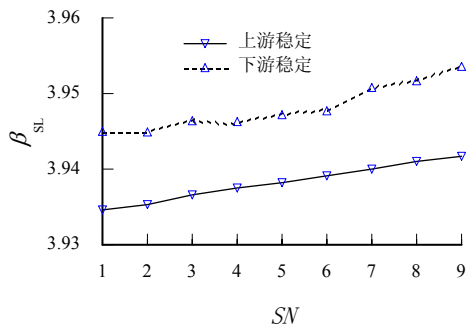
Distribution of Safety factor of sliding for whole dike section

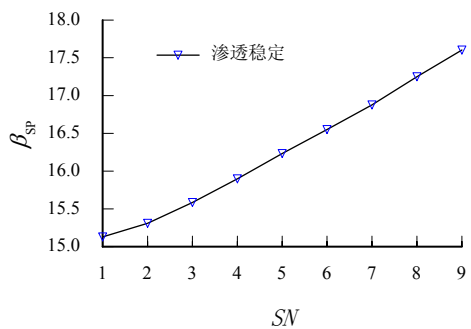
For Whole Dike Section



For Each Dike Subsection



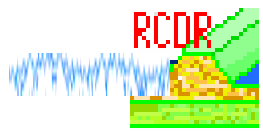
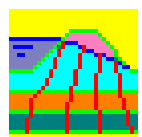
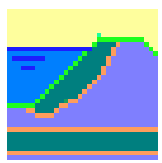




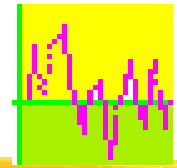
Failure Modes

Modes	Dam (China)	Yangtze
Piping	38	54.5
Overtopping	30	
Stability inner slope		15
Stability outer slope	15	
Erosion inner slope		10
Erosion outer slope		
Overflow		

Limit State Equation

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	$z_3 = F_{SL} - 1 = M_r / M_o - 1$	

Calculation Methods



J-C method（FORM）

Monte Carlo method

Detailed information about these methods can be found in related literatures

Monte Carlo Method

Involves these following steps

- (1) Probabilistic distribution models and distribution parameters of the variables related to reliability analysis are determined;
- (2) Normally distributed random numbers; The first random sampling of all variables is done, and the result is used in the reliability function;
- (3) Repeat random sampling independently for the total number of simulations , and then failure probability is estimated.

Monte Carlo Method

$$P_{\mathrm{f}} = P(g(x_1, x_2, \cdots, x_n) \le 0)$$

$$I(g(x_1, x_2, \cdots, x_n)) = \begin{cases} 1, & g(\cdot) \le 0 \\ 0, & g(\cdot) > 0 \end{cases}$$

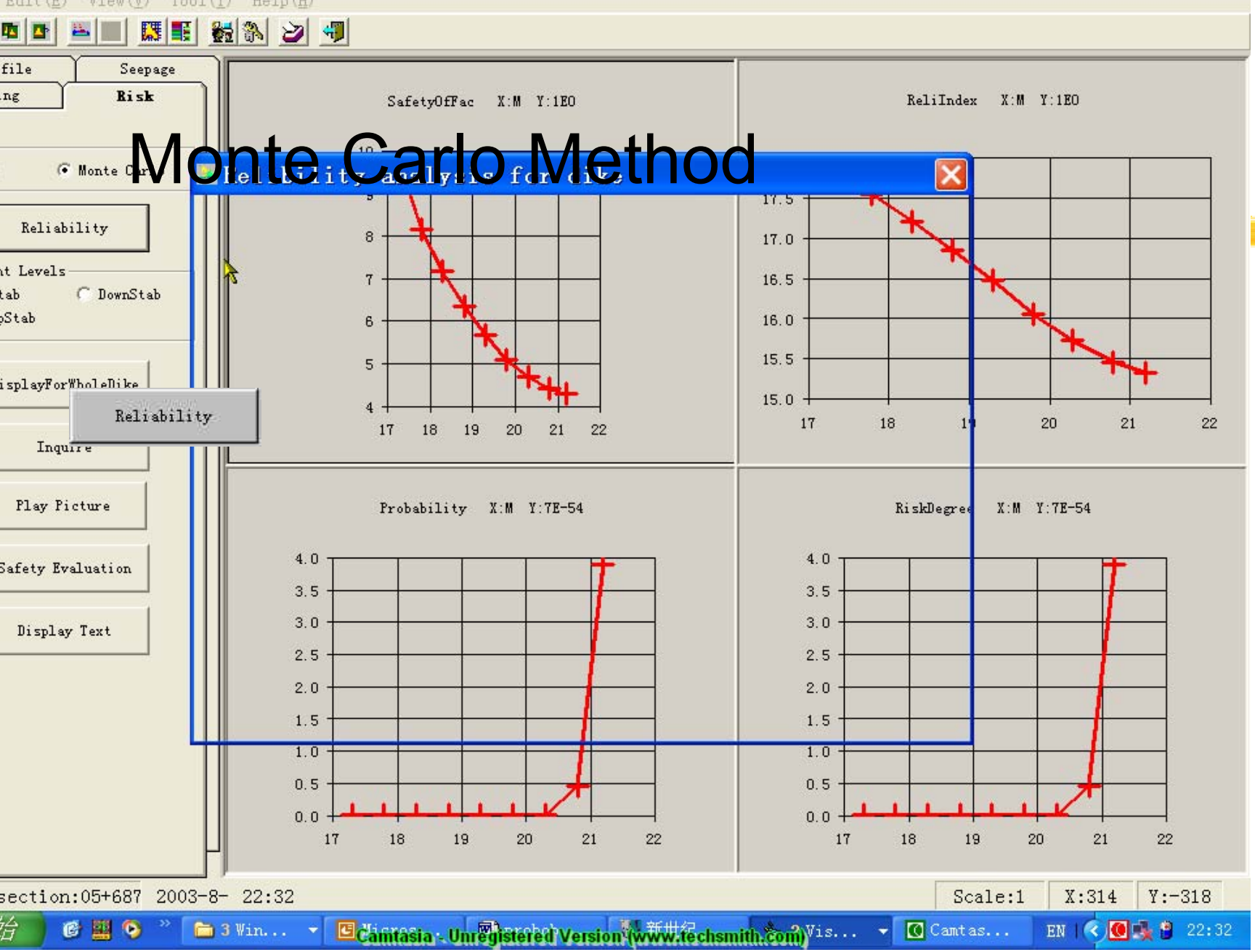
$$\hat{P}_{\mathrm{f}} = \frac{1}{N} \sum I(g(x_1, x_2, \cdots, x_n) \le 0) = \frac{M}{N}$$

M is the number that $g(\cdot) \le 0$

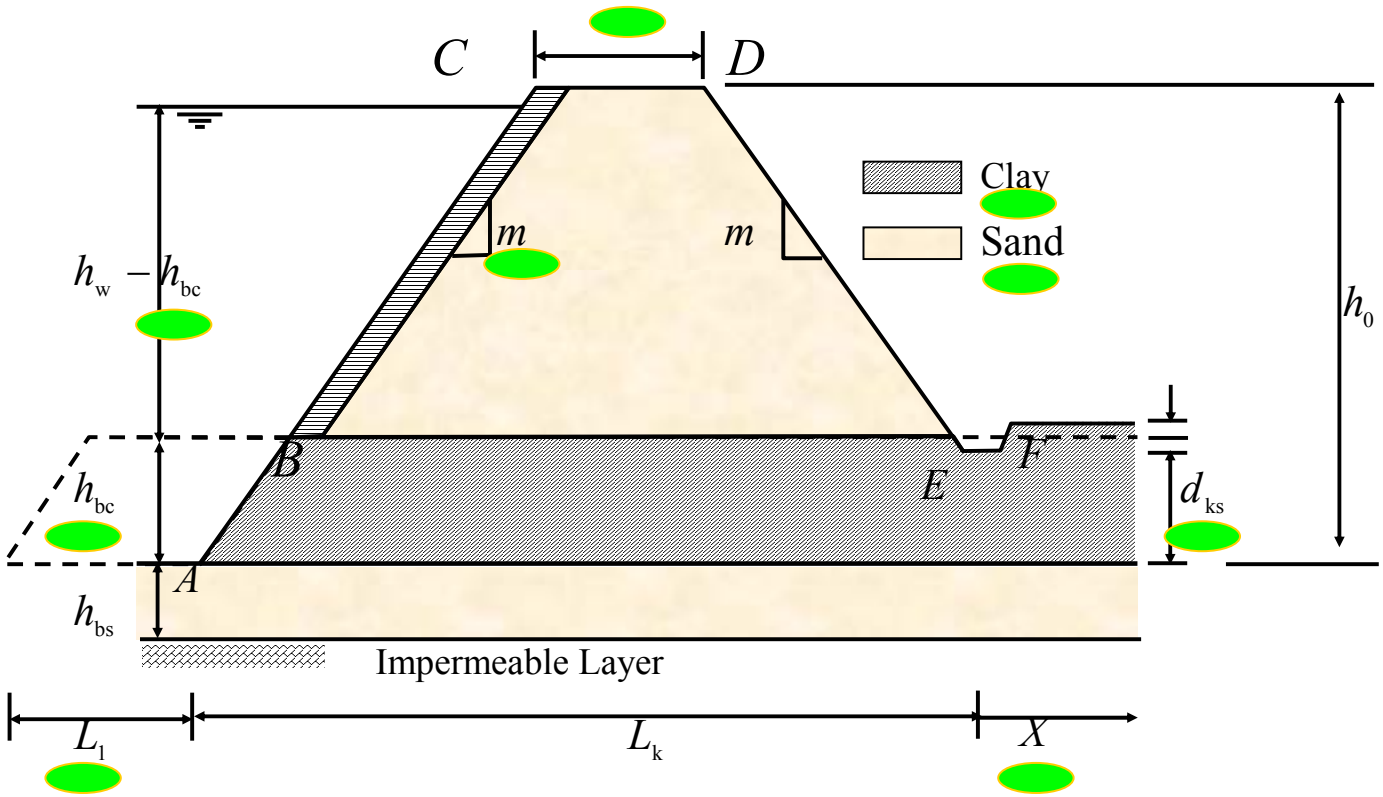
N Is the total number of simulations

Theory Demonstration **Programme Display**

Monte Carlo Method



Typical Dike Section Used This Study



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

Geometry and Geotechnical Parameters

Variable	Description	Unit	Type	Mean value	Standard Deviation
h_{bc}	Thickness of clay	m	DV	3.5	
L_1	Width of foreland	m	DV	0.0	
m	Slope ratio		DV	2.5	
w	Crest width	m	DV	5.0	
t_{sb}	Thickness of piping-berm	m	DV	0	
X	Width of piping-berm	m	DV	0	
h_0	Height	m	DV	11.0	
h_{bs}	Thickness of sand	m	DV	2.5	
γ_{nk}	Buoyant unit weight of clay	kN/m3	DC	9.0	
γ_w	Unit weight of water	kN/m3	DC	10.0	
γ_{sb}	Bulk gravity of piping-berm	kN/m3	DC	18.0	
d_{ks}	Effective thickness of clay	m	RV	3.5	0.7
h_w	Flood water level	m	RV	8.3	0.9
k_c	Permeability coefficients of clay	m/s	RV	10-8	2*10-8
k_s	Permeability coefficients of sand	m/s	RV	10-5	0.75*10-5

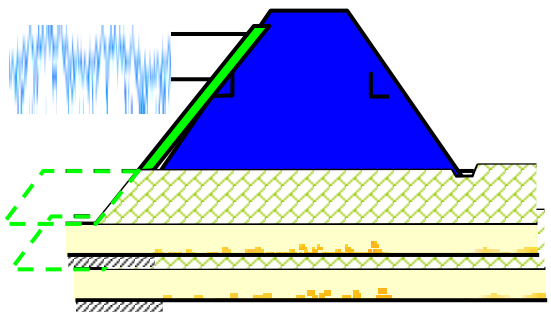
DV--- Design variables; DC--- Deterministic Constants; RV---Random Variables

Modelling of Overtopping Mechanism

$$z_1 = h_0 - h_{\mathrm{w}} - h_s - e$$

h_0	height of dike crest	Normal distribution	11.0m	0.051m
h_{w}	swash height	exponential distribution	8.34m	0.9m
h_s	surge height	Normal distribution	0.638	0.44
e		Normal distribution		

Overtopping---ResultA



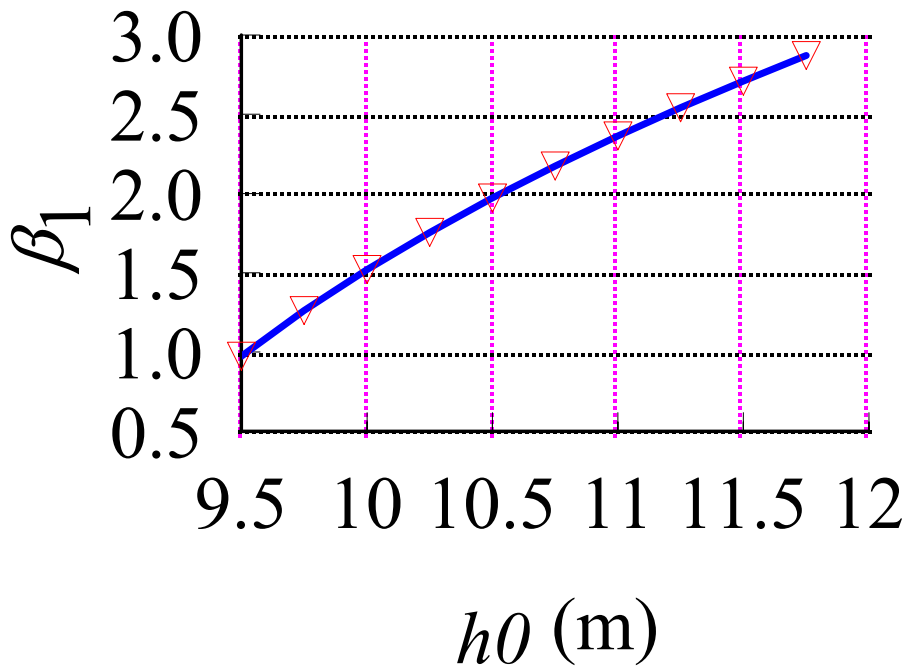
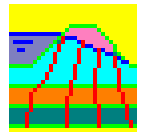


Fig. 2 Relation between height of dike and reliability index

Modelling of Piping Mechanism



safety factor

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

residual head of weak permeable stratum

$$h_{ap} = \frac{h_w}{1 + A * L_k + \tanh A * L_1} e^{-AX}$$

a **coefficient**

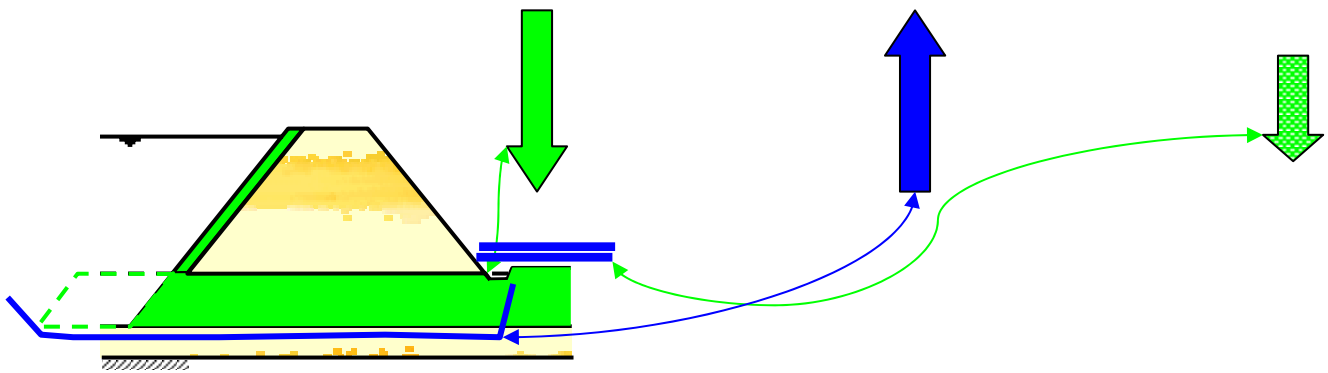
$$A = \sqrt{\frac{k_c}{k_s h_{bc} h_{bs}}}$$

effective seepage path length

$$L_k = 2 * m * h + w + m * h_{bc}$$

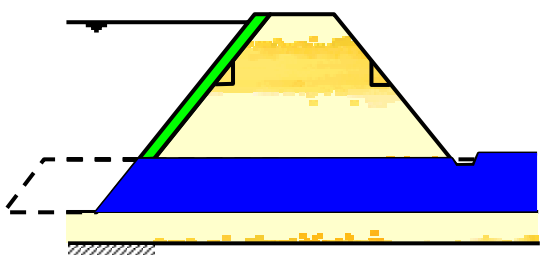
Modelling of piping mechanism

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



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

Piping---ResultB



$$F_{CN} = \frac{\gamma_{nk} d_{ks}}{\gamma_w h_{ap}}$$

$$y = kx$$

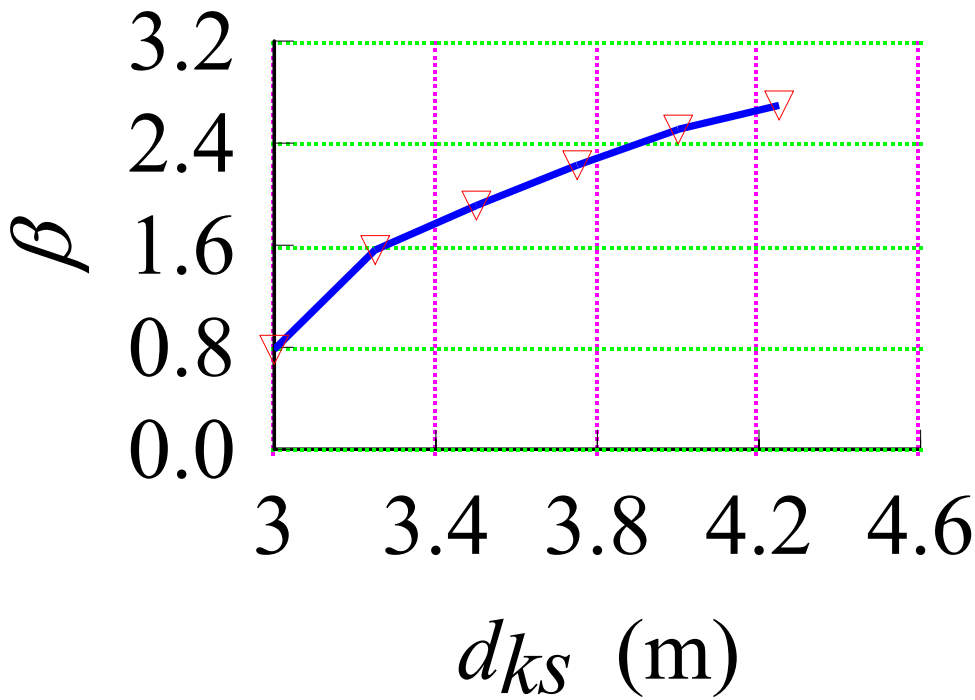
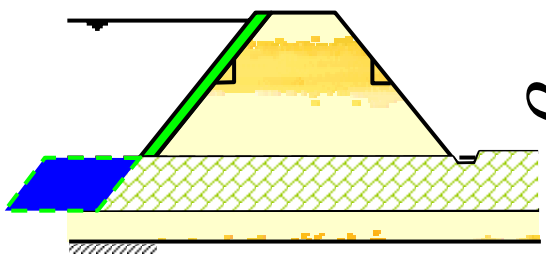


Fig. 3 Thickness of clay stratum

Piping---ResultC



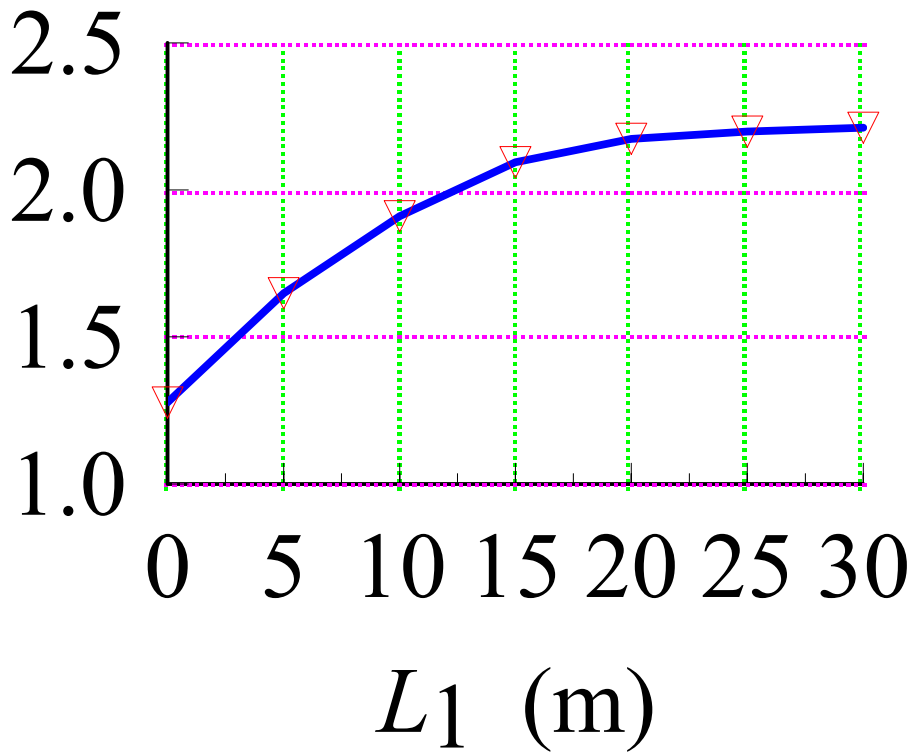
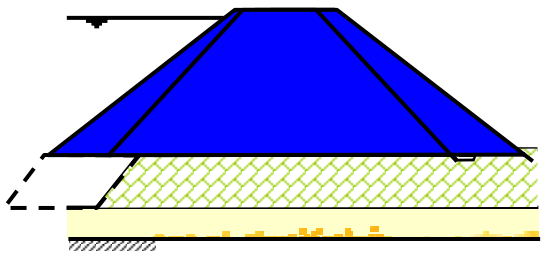


Fig. 4 Width of foreland

Piping---ResultD



Flattened to 1V on 5H

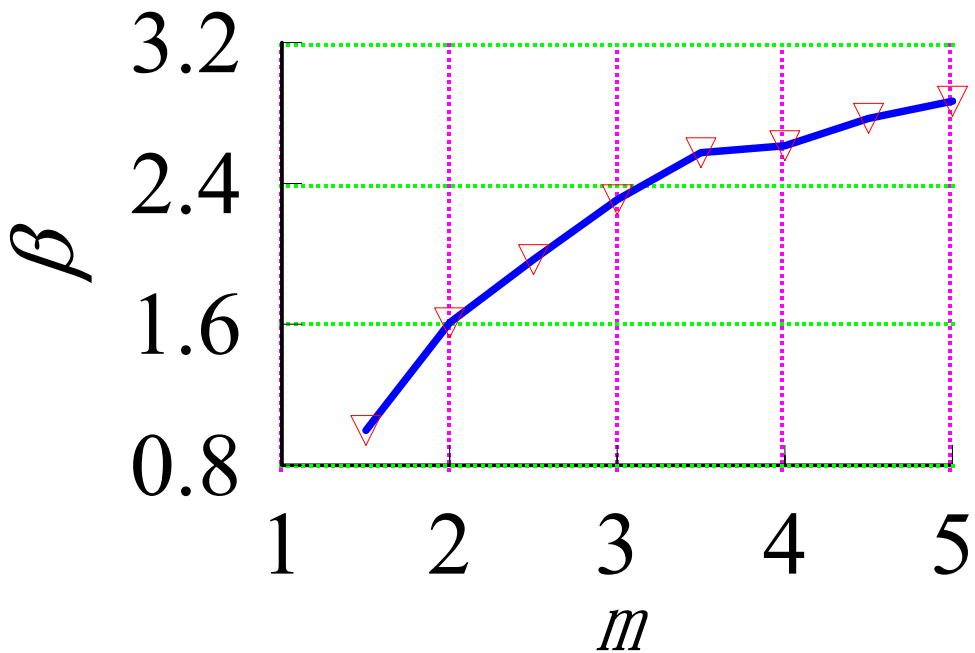
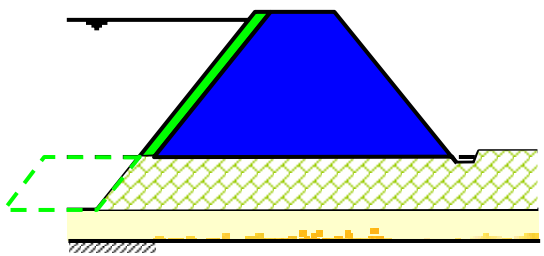


Fig. 5 Slope ratio

Piping---ResultE



widen

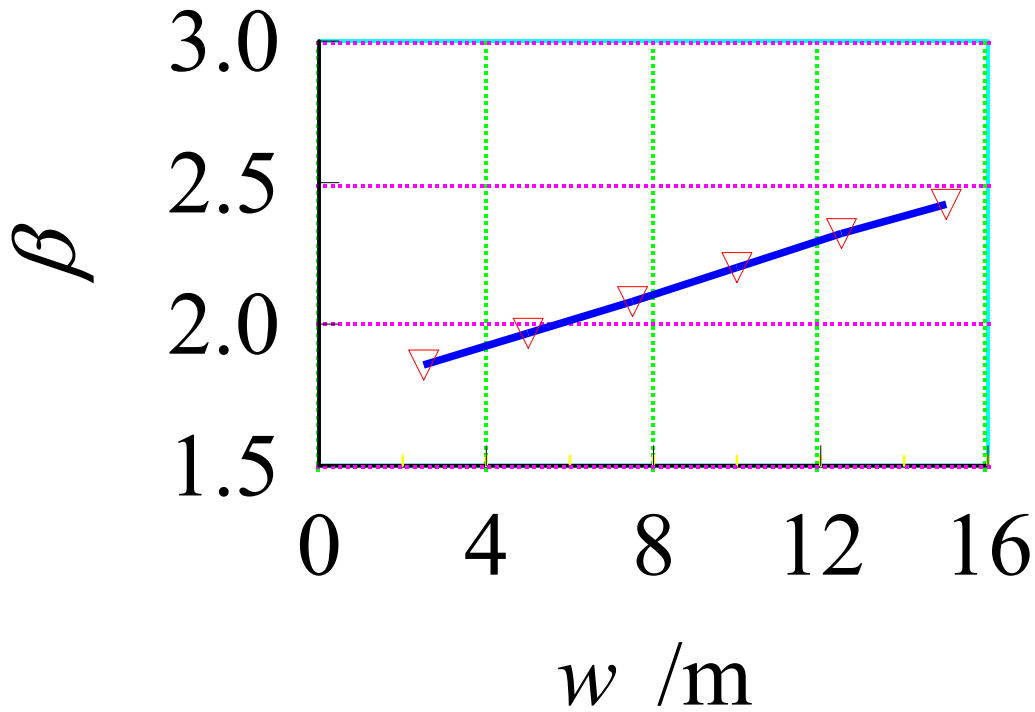
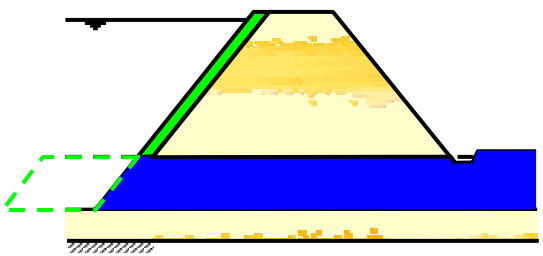


Fig. 6 Crest width

Piping---ResultF



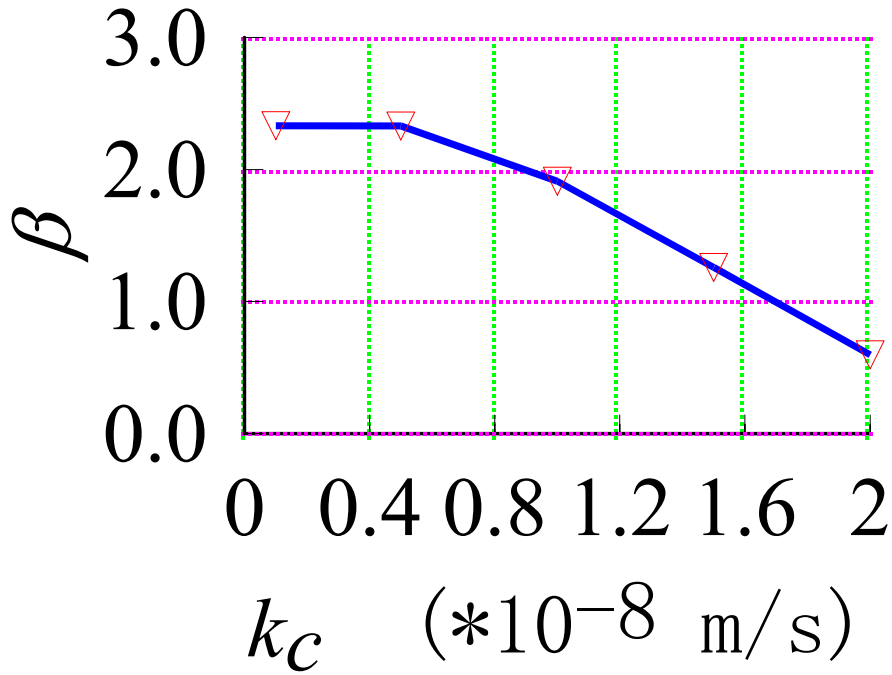
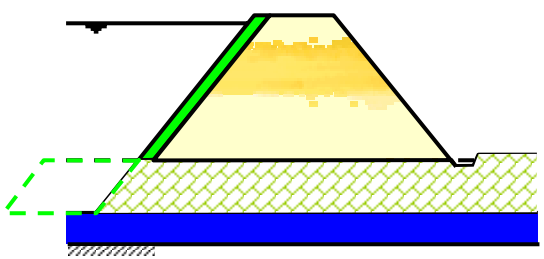


Fig. 7 Permeability coefficient of clay

Piping---ResultG



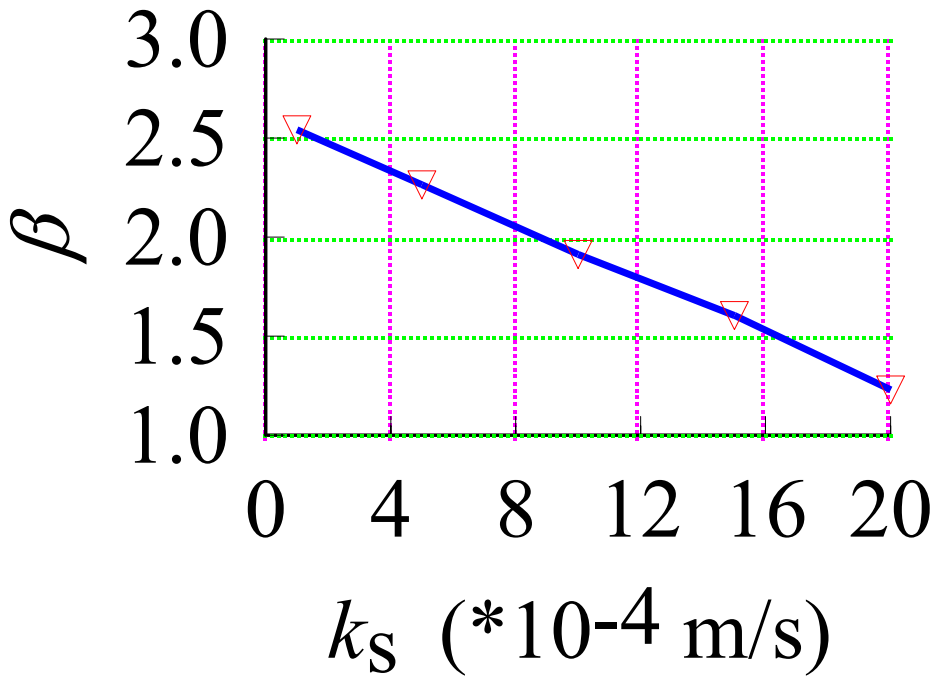
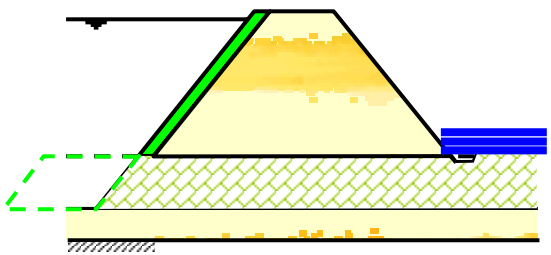


Fig. 8 Permeability coefficient of sand

Piping---ResultH



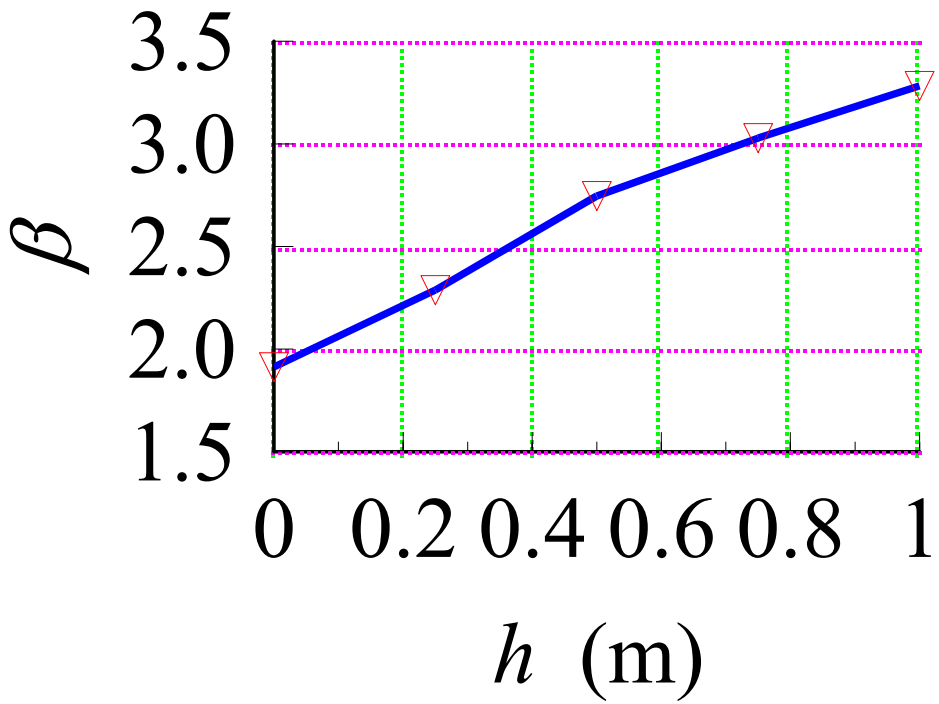


Fig. 9 Thickness of piping-berm

Piping---ResultI

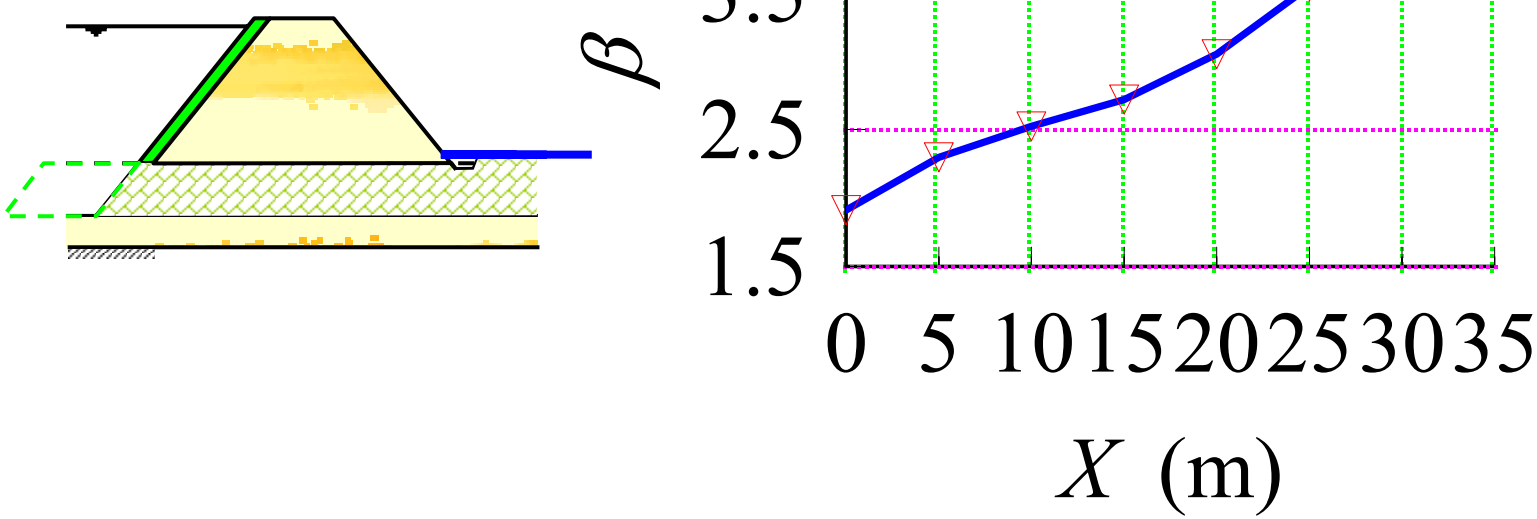
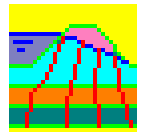
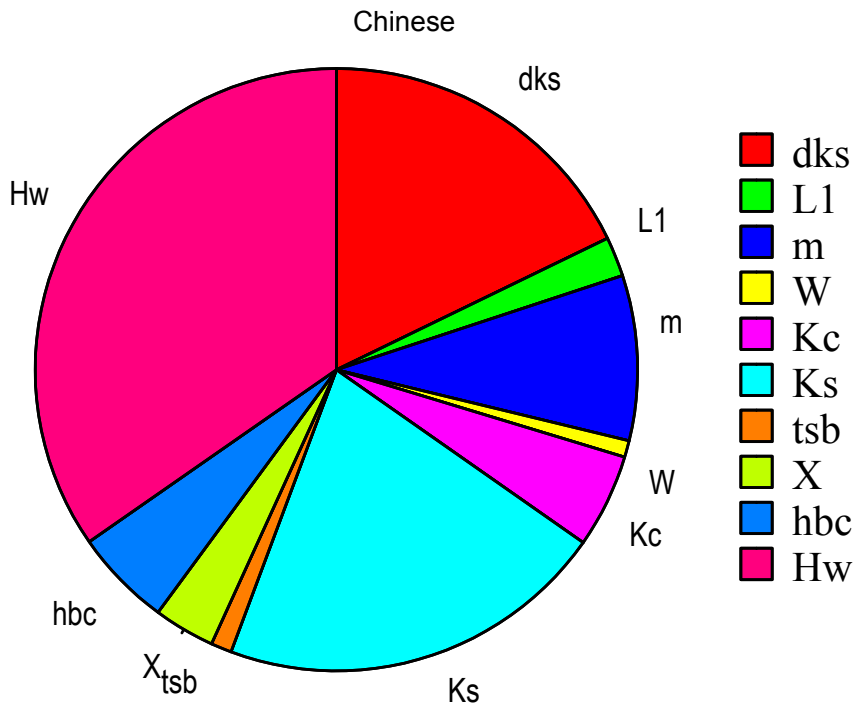


Fig. 10 Width of piping-berm

Piping---ResultJ

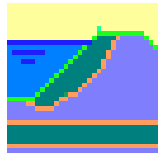


As shown in right Figure, the variables that contribute most to the Reliability index against piping are the water level, thickness of clay layer, seepage coefficient of sand, and the slope ratio.



Relative influence of the variables on Reliability Index

Modelling of Sliding Stability



simplified Bishop method

$$F_{\mathrm{SL}} = \frac{\sum \frac{1}{m_{\alpha i}} \left[c'_i b_i + \left(W_i - u_i b_i \right) \tan \varphi'_i \right]}{\sum W_i \sin \alpha_i}$$

$$m_{\alpha i} = \cos \alpha_i + \frac{\tan \varphi'_i \sin \alpha_i}{F_{\mathrm{SL}}}$$

$$z_3 = F_{\mathrm{SL}} - 1 = M_{\mathrm{r}} / M_{\mathrm{o}} - 1$$

Slope Stability of Dike

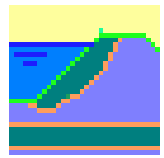
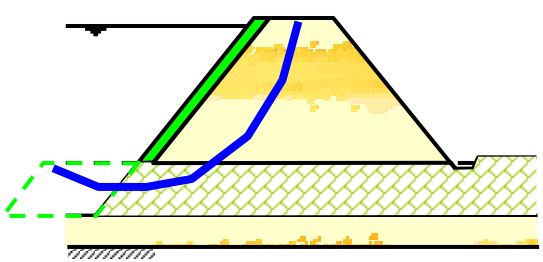


Table 1 Statistic of geotechnical parameters

Symbol	Name/unit	Distribution type	Mean value	Standard deviation
c	Cohensive (kPa)	Normal	12.54	2.8
ϕ	Inner friction angle(0)	Normal	21.58	3.5
γ	Bulk gravity (kN/m3)	Normal	18.84	3.1

Sliding---ResultK



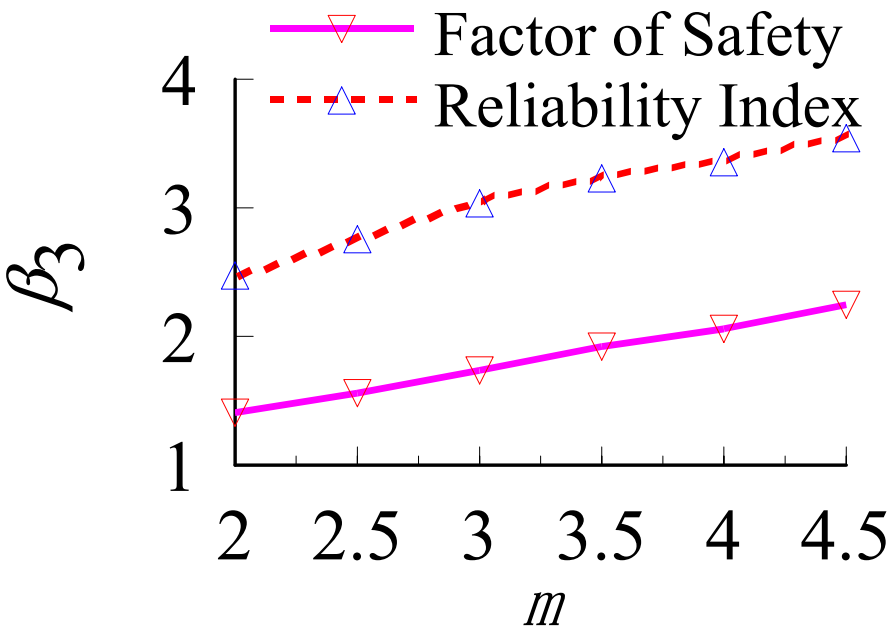
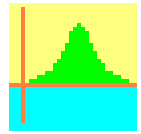


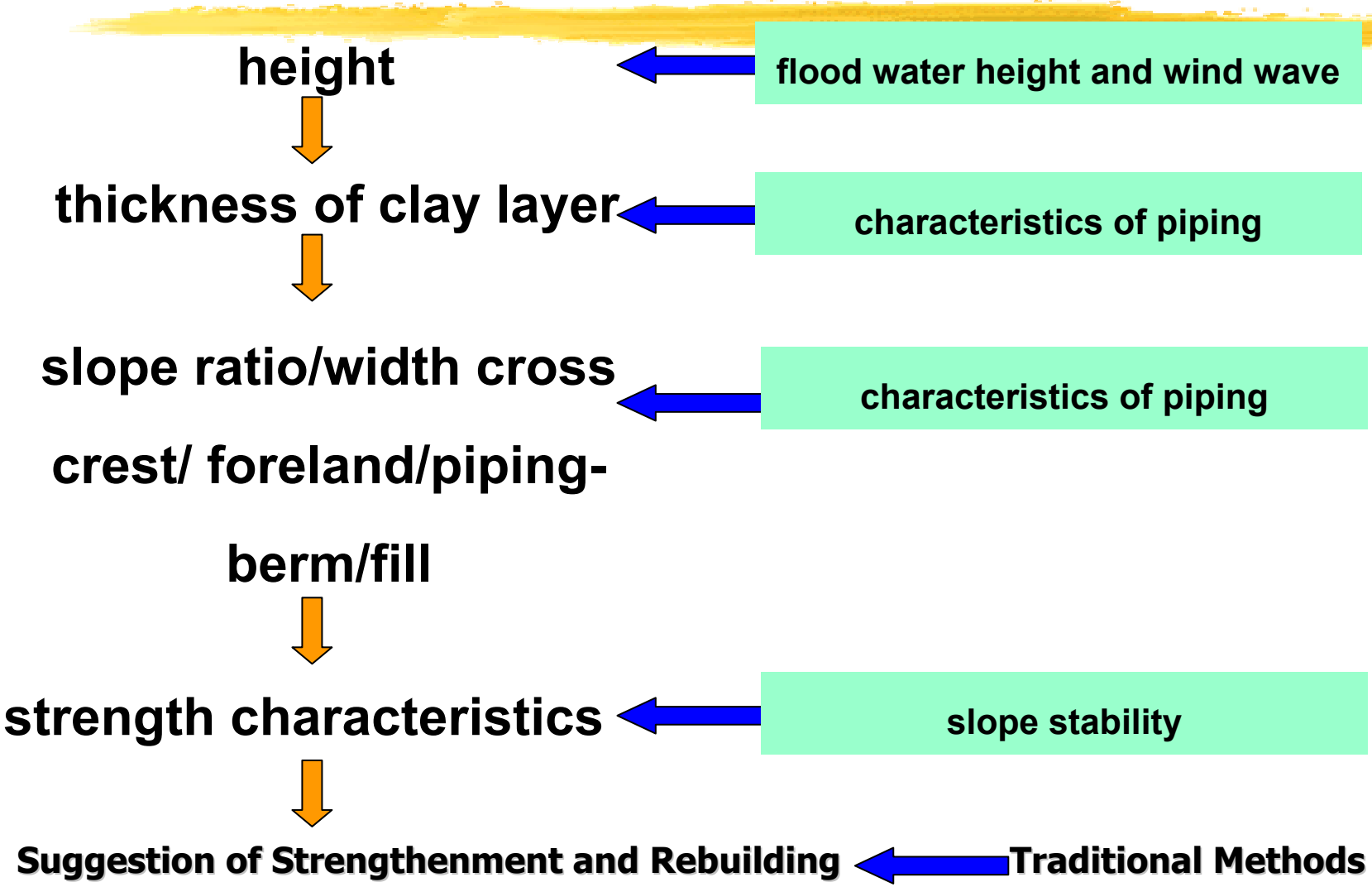
Fig. 11 Influence of slope ratio

Probabilistic Design Process

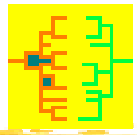


- **The height (flood water height and wind wave)**
- **The thickness of clay layer (characteristics of piping)**
- **The slope ratio, width cross crest, width of foreland, width of gland, thickness of gland and seepage characteristics of fill (piping).**
- **Strength characteristics of soil (slope stability analysis).**
- **The revetment, drainage facility of slope surfaces, impervious facility and drainage facility**

Diagram of Design Process



Some Conclusions---(A)



(1)The reliability index of overtopping increases with the height of dike.

(2)The reliability index of seepage stability of dike foundation increases with the slope ratio, width cross crest, width of clay layer of dike foundation, width of foreland, width and thickness of piping-berm behind dike.

Some Conclusions---(B)

(3) The reliability index of seepage stability of dike foundation decreases with the increase of seepage coefficient of clay layer and sand layer.

(4) The reliability index of slope stability increases with the slope ratio of dike.

Areas for Further Study

- Cost-benefit analyses in a probabilistic framework should be performed in the future, for the proposed existing dike improvement
- Shortcoming ---data collect?/!
- Flood duration. Some levees may be subjected to significant water heights for many months. When this occurs, the phreatic surface within the levee will rise, increasing pore pressure and increasing the risk of failure due to under-seepage and slope stability.

谢谢各位同仁

谢谢光临

Thanks

谢谢光临

Cooperation

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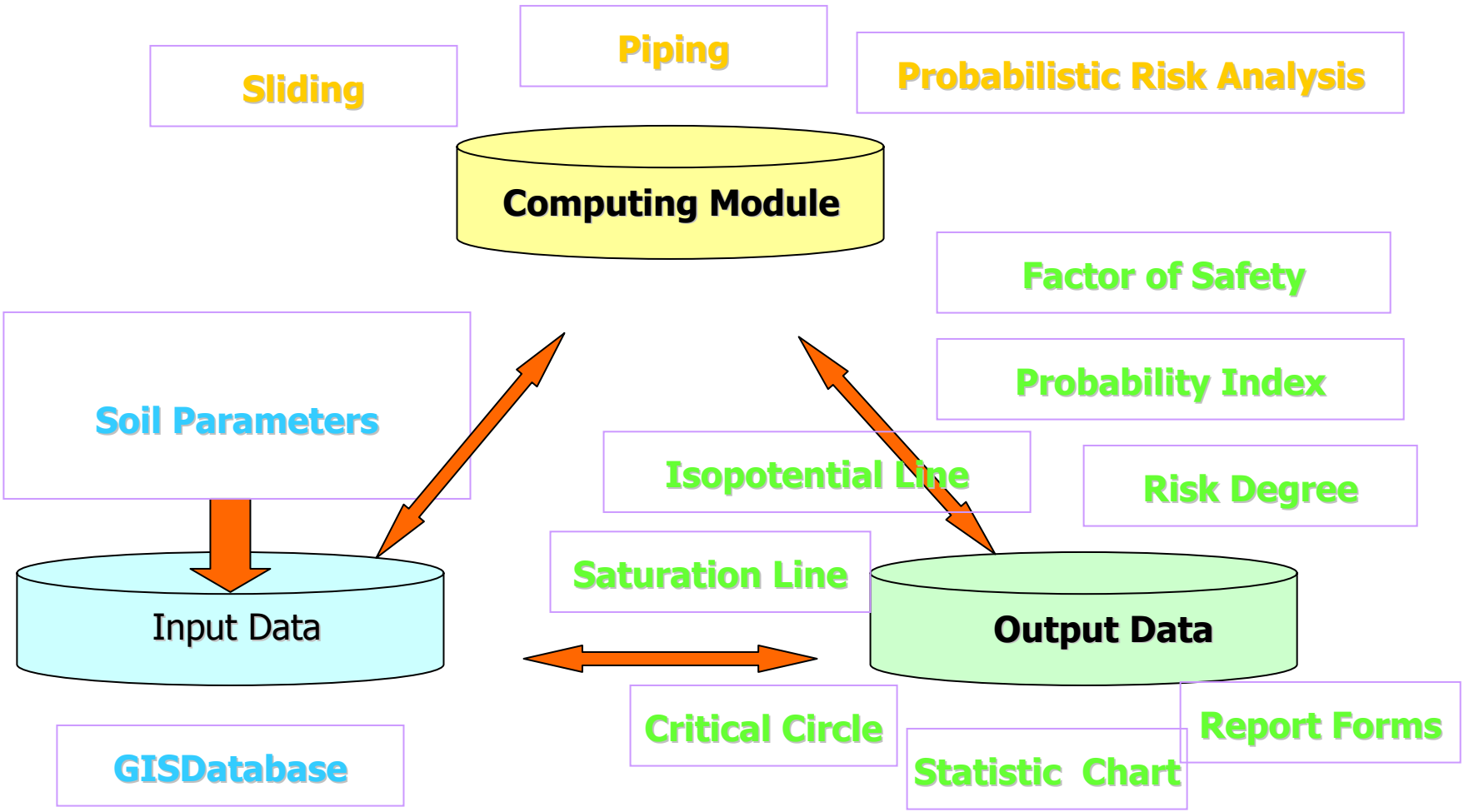
Safety Assessment and Decision Support Software System of Dike

SADSS



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