Completely-Weathered Sandstone Slope Failure During Highway Construction and its Remedy

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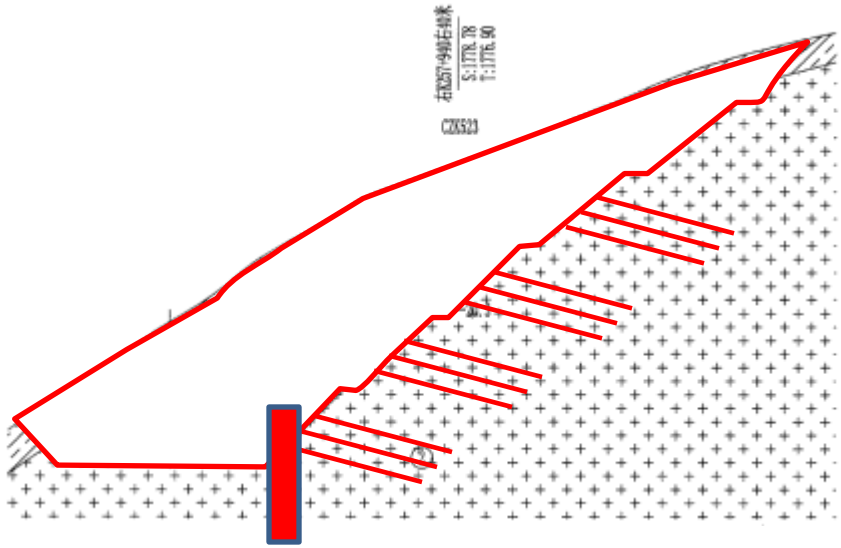
Slope stability problems in highway construction

- With the continuous development of China's economy, highway construction are increasing.
- Slope failure often occurs in highway construction, which causes increase of project budget and destruction of environment.

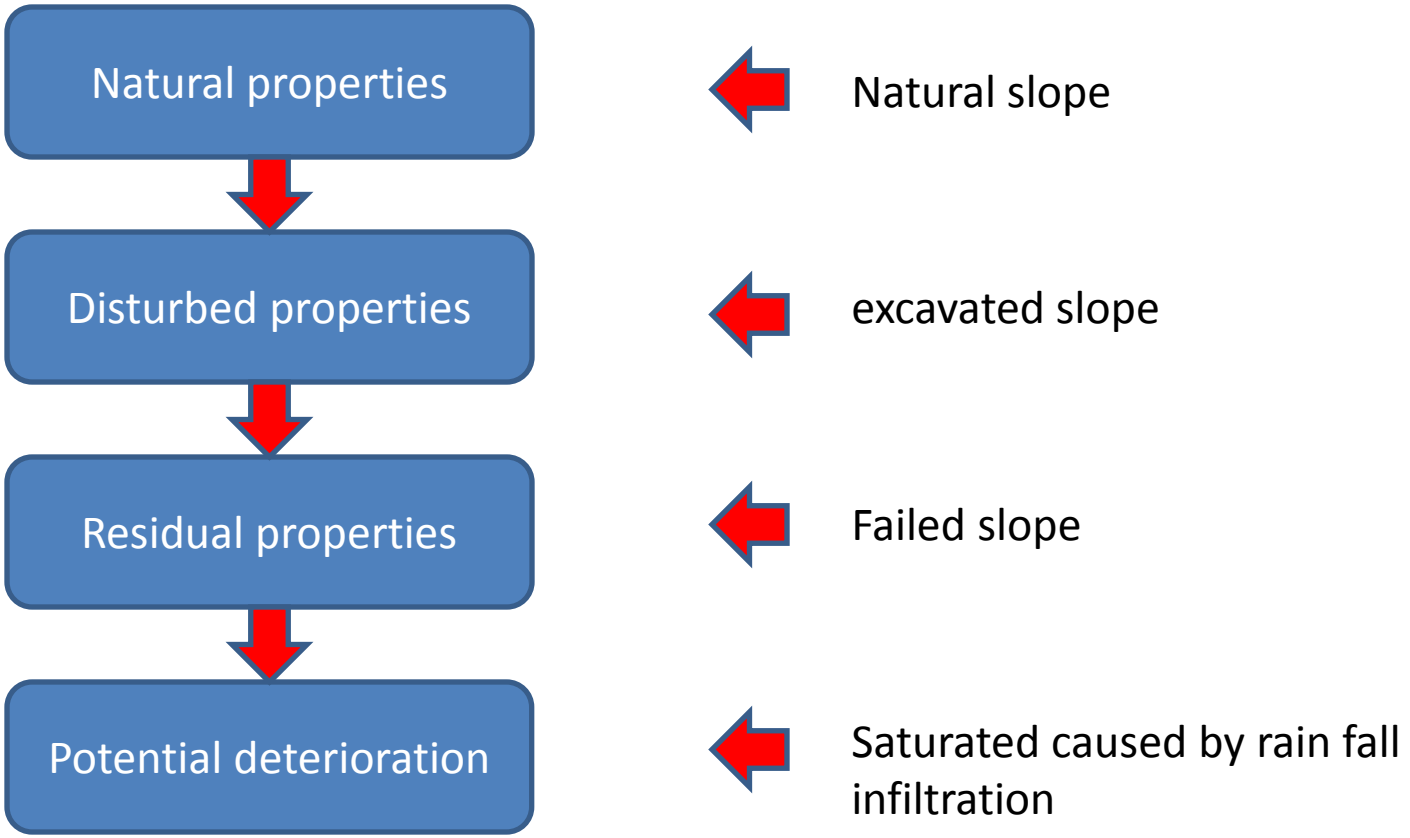
Conventional slope design method

- Most slopes are excavated and then reinforced.

- However, with the disturbance of excavation and development of rock and soil deformation, the properties of rock and soil are weakened gradually, which is more significant in soft rock and loose deposit soil slopes.



The deterioration of rock and soil properties



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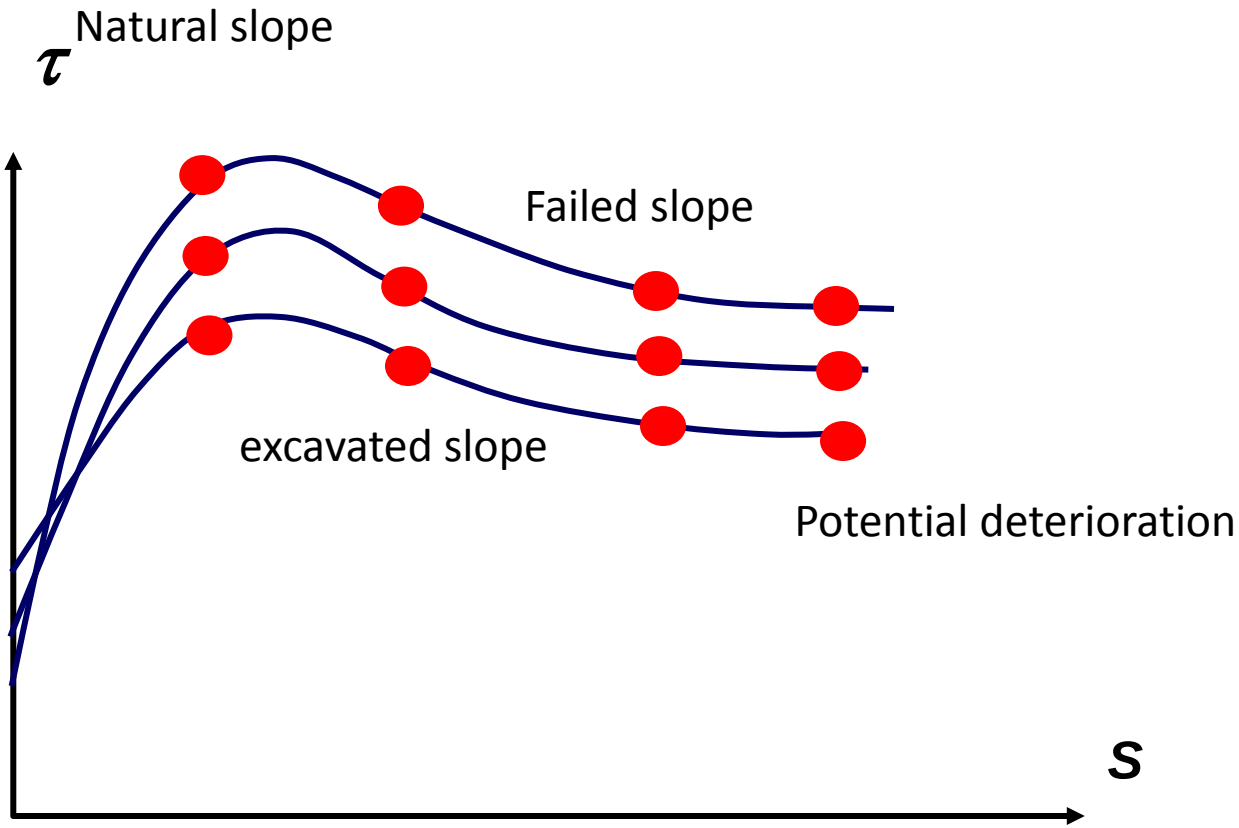
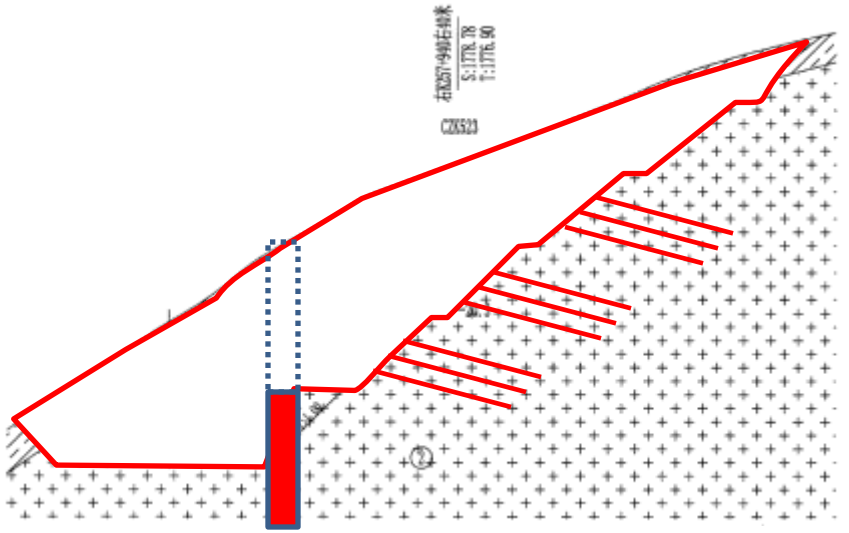


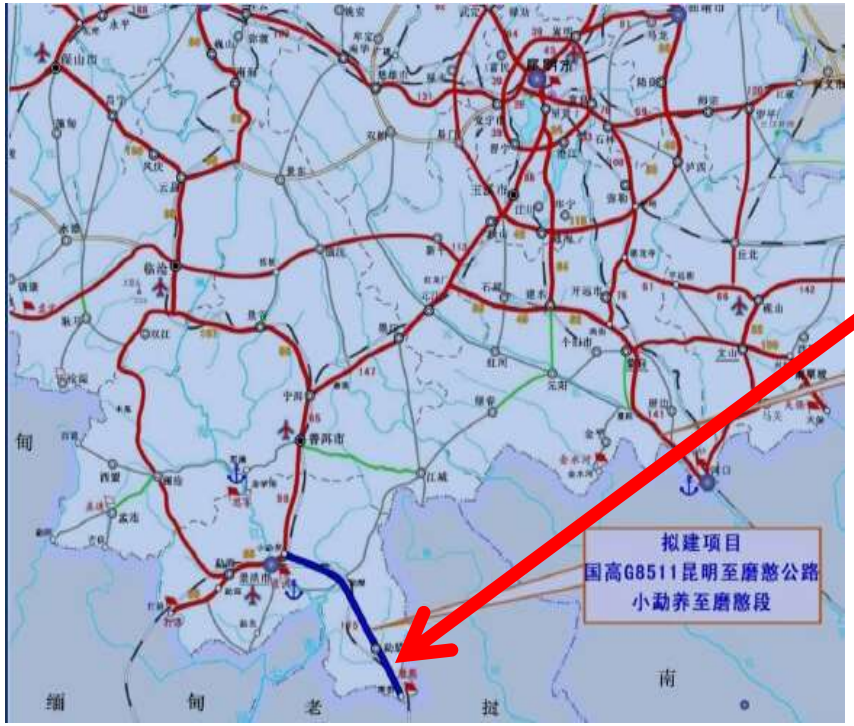
Active slope design method

- In order to make full use of **the inherent rock and soil strength**.
- **Active slope design** method is recommended in soft rock and loose deposit soil slopes.
- **Pre-reinforcement measures** are employed and then the slope is excavated.



Case study of CWS slope failure

Completely-Weathered Sandstone



The slope is located in xiao-mo highway, Yunnan, China

About the slope failure

- The slope is 100m high weathered sand stone slope.
- Slope failure occurred during excavation. Volume is About 300,000m3.
- No reinforcement is employed before the slope failure.

Site investigation after the slope failure

Sliding body is CWS

CWS

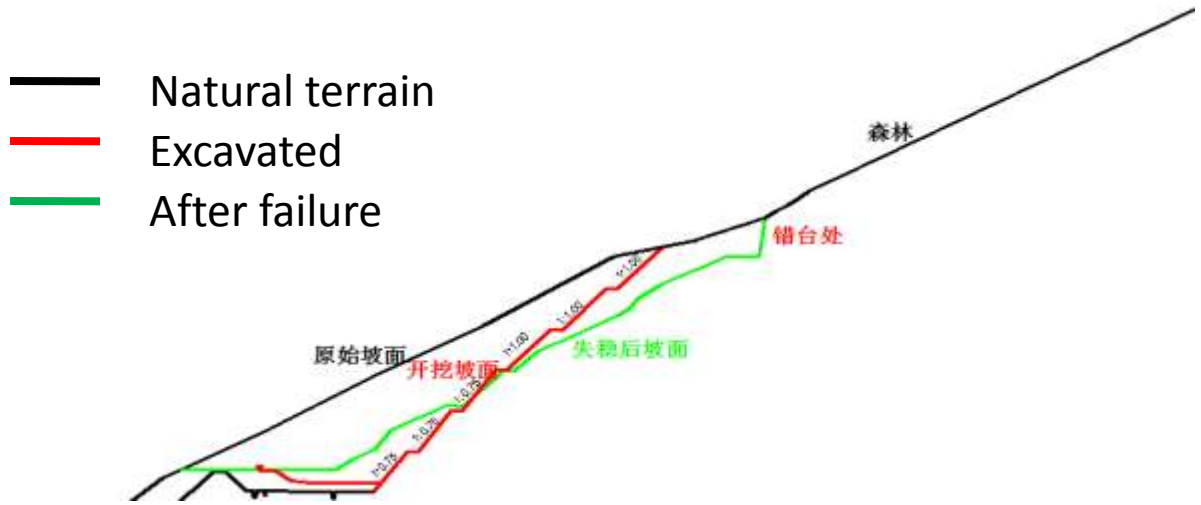
Slip surface

Mudstone

Most of the slip surface are interface of CWS and underneath mudstone.

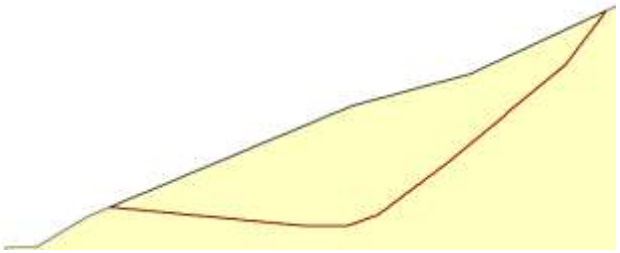
CWS shear strength deterioration process

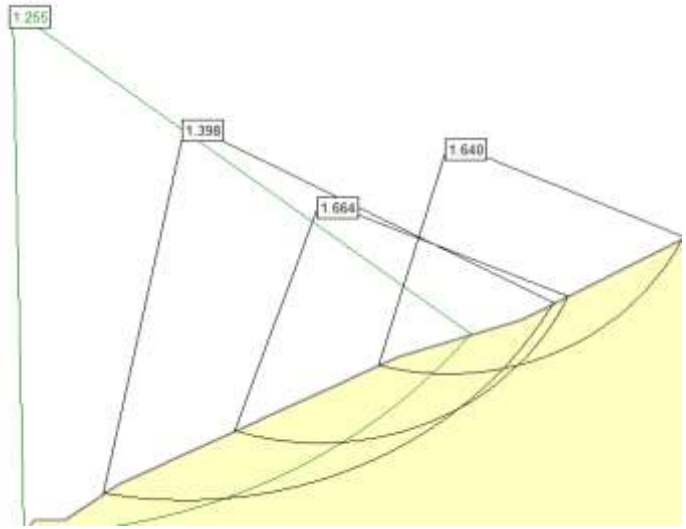
- The strength deterioration process is obtained by back-analysis using limit equilibrium method(LEM).
- 4 stages are considered:
  - natural slope, shear strength C1,ϕ1
  - excavated slope, shear strength C2, ϕ2
  - failed slope, shear strength C3, ϕ3
  - Potential deterioration shear strength C4, ϕ4



CWS shear strength deterioration process

- Natural slope-natural properties





Failed slip surface
Fs=1.76

Critical slip surface by auto-search
Minimal Fs=1.25

consistent with natural slope stability state

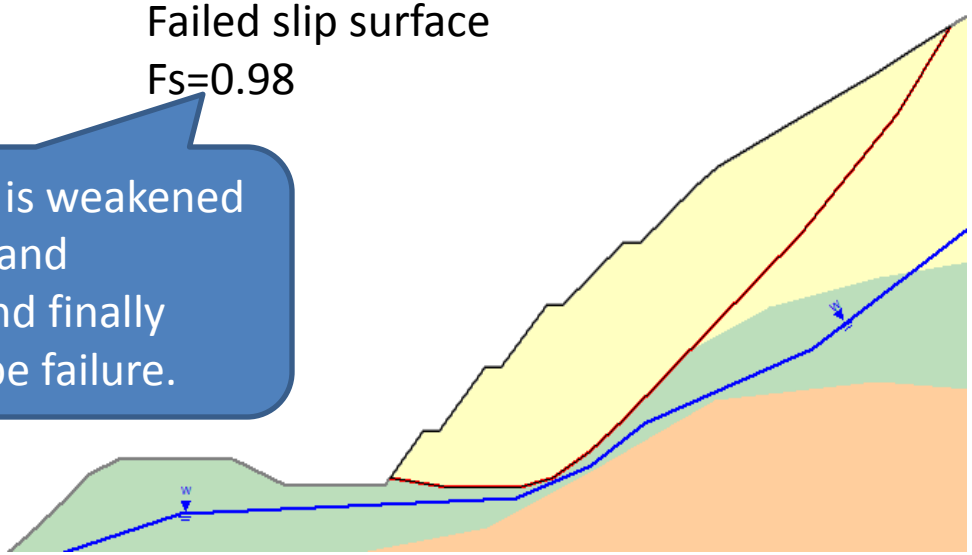
Shear strength C1=33kPa,ϕ1= 24°

CWS shear strength deterioration process

- Excavated slope-disturbed properties

Failed slip surface
Fs=0.98

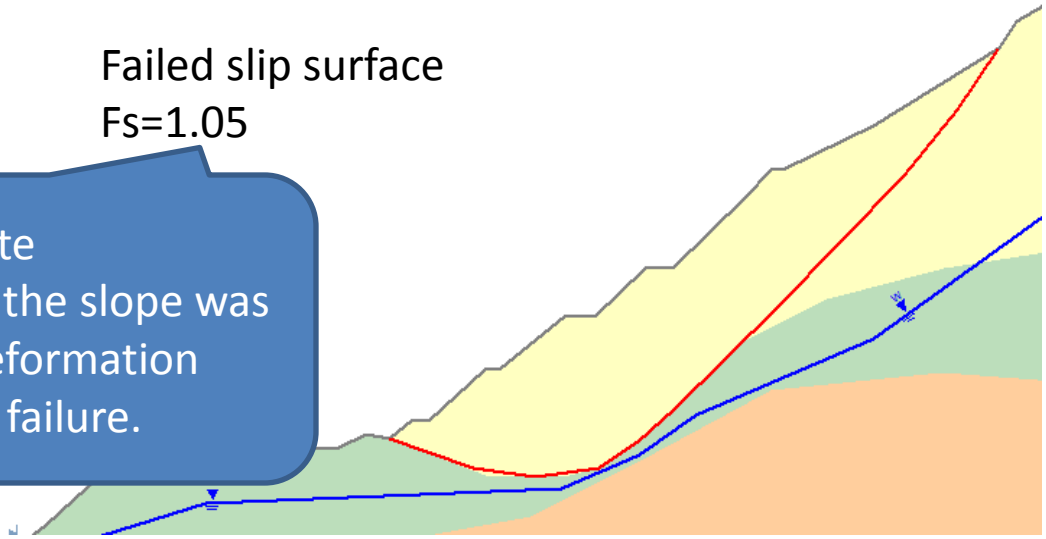
Shear strength is weakened by excavation and deformation and finally causes the slope failure.



Shear strength C2=25kPa,ϕ2= 23°

CWS shear strength deterioration process

- Failed slope-residual properties



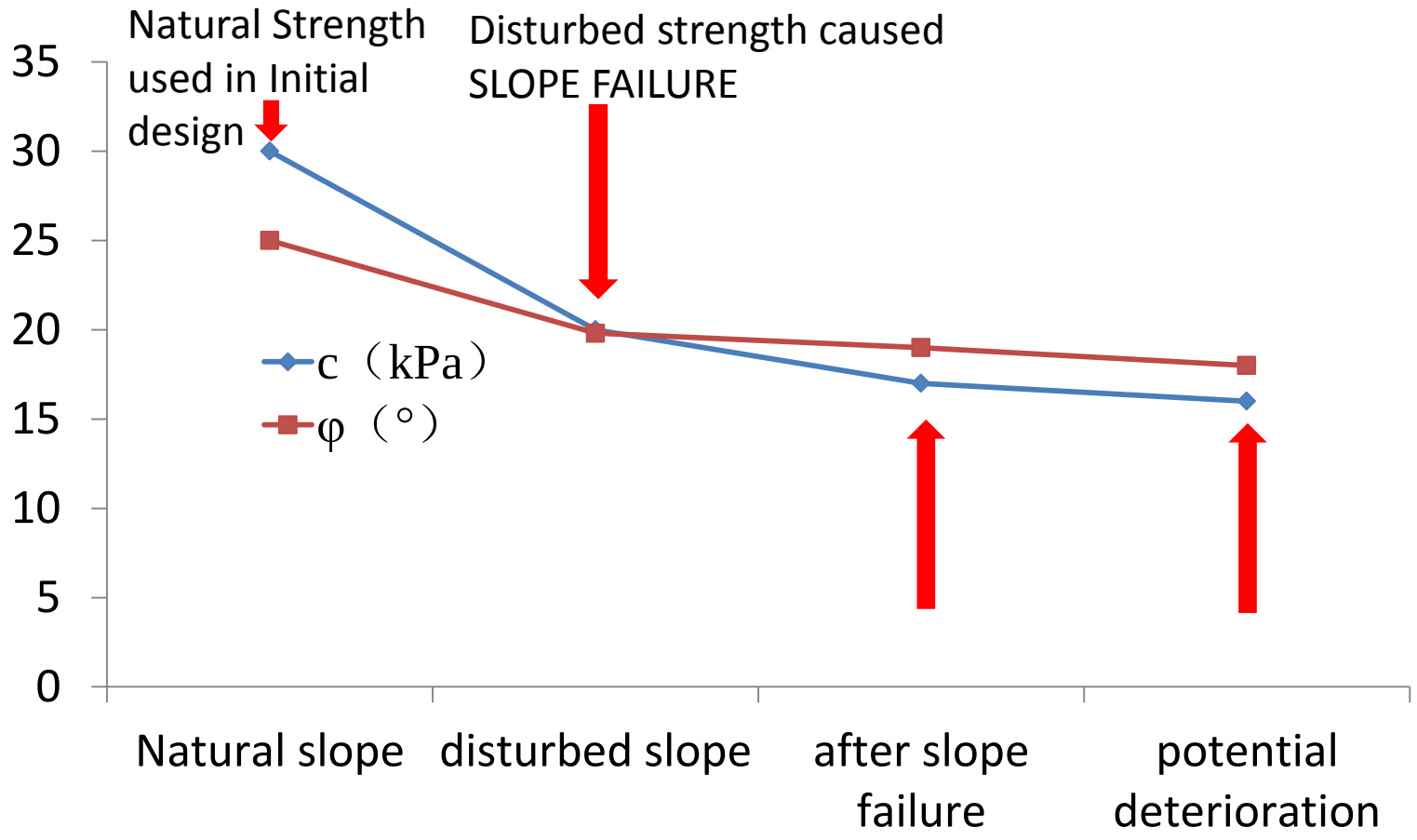
Shear strength C3=21kPa,ϕ3= 10°

CWS shear strength deterioration process

- potential properties deterioration
  - The slope failure had occurred in **dry season**(Dec. 2015)
  - The **water content** of the slip surface is **9.28%** .
  - The residual shear strength will be **deteriorated further** if the sand stone is **saturated** by rain fall infiltration.
  - According to the test results of correlation of rock/soil shear strength and water content in **literature**, the saturated shear strength is determined as

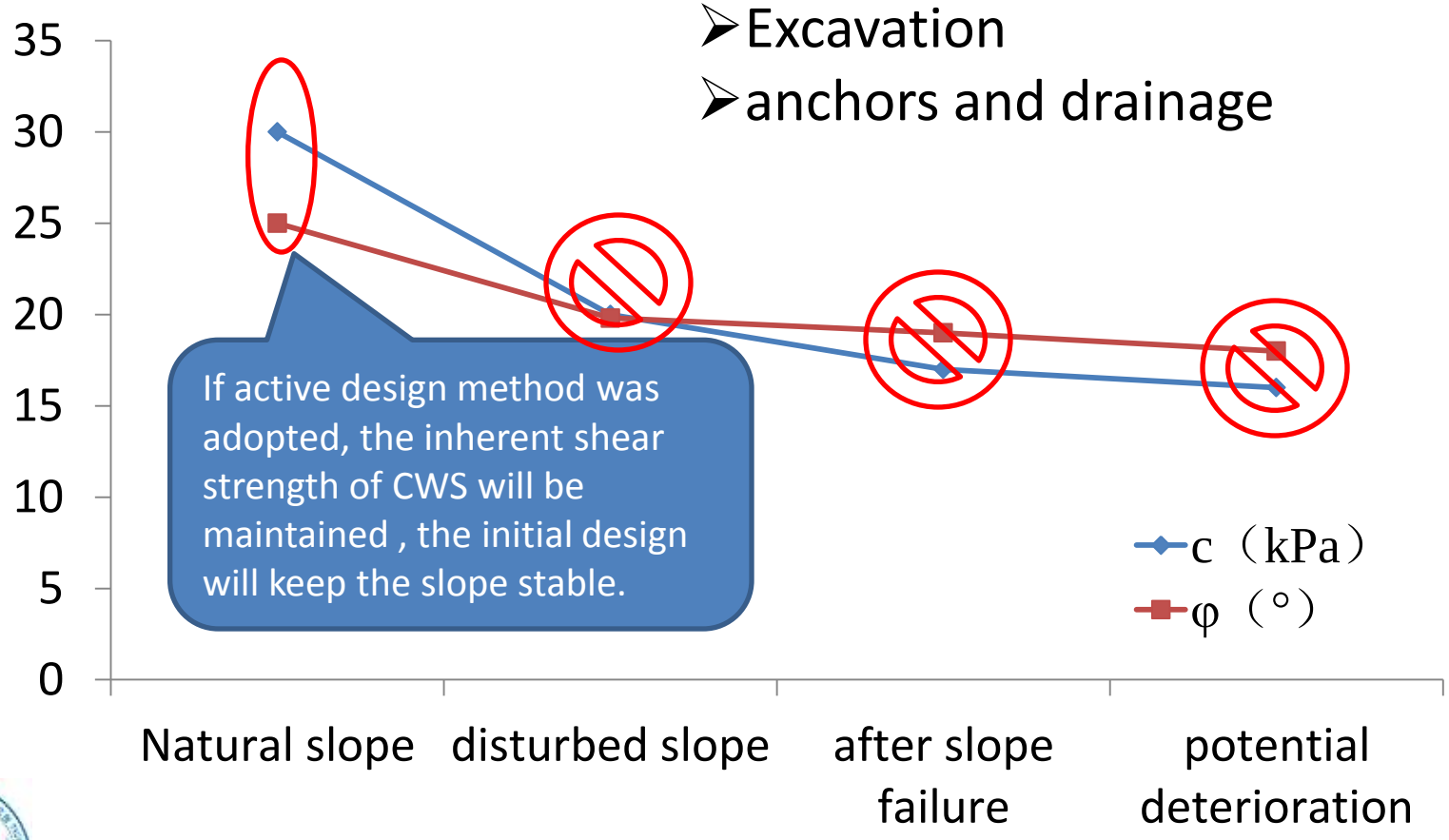
$C4=21kPa, \phi 4= 10^{\circ}$

CWS shear strength deterioration process



Active design of the slope

- anti-sliding piles(pre-reinforcement)
- Excavation
- anchors and drainage



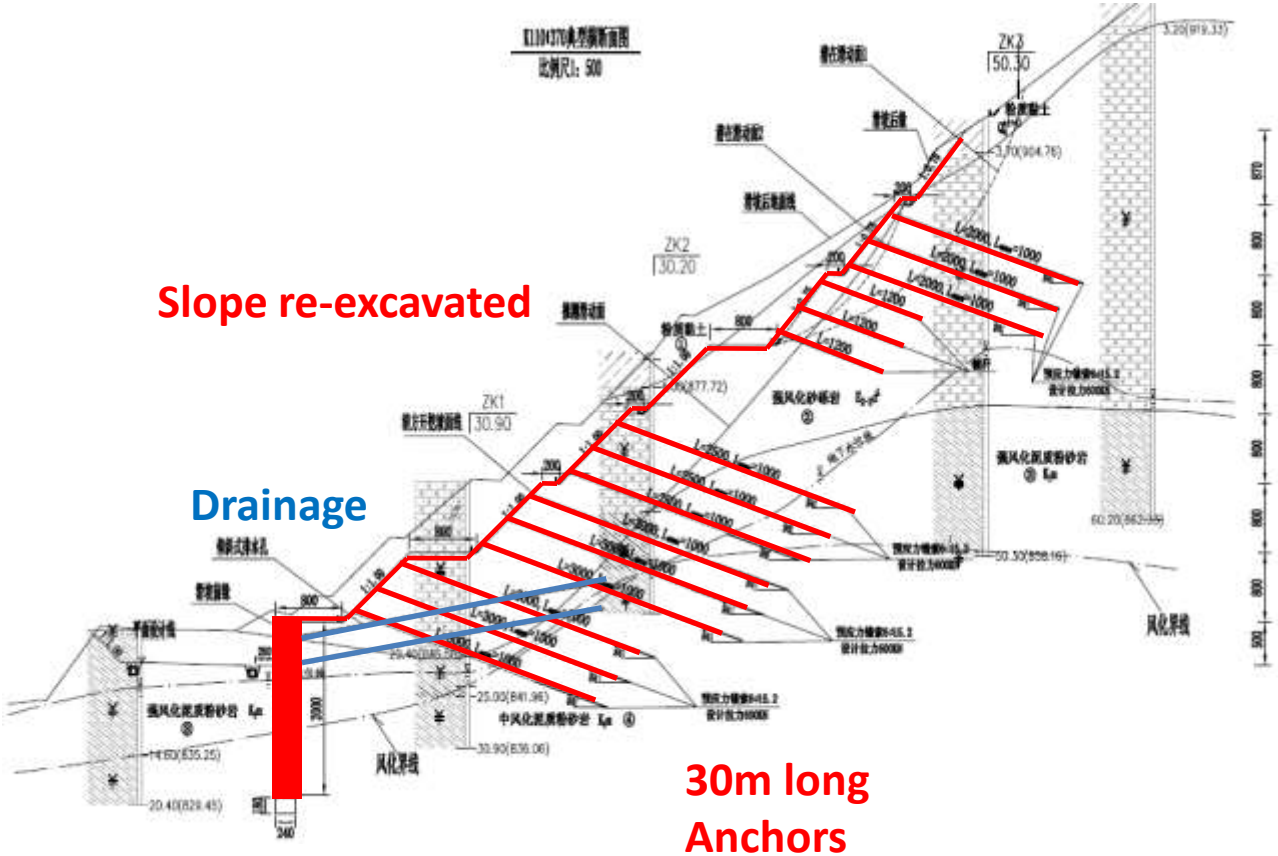
Remedial measures

- The failed slope was re-designed according to the deteriorated shear strength of CWS.
- The recommended shear strength of CWS is

$C4=21kPa, \phi 4= 10^{\circ}$

- 20m long anti-sliding piles are employed(totally 15 piles).
- The slope was re-excavated and surface reinforcement was re-designed as 30m long anchors.
- Drainage measures are employed.

Remedial measures



Remedial measures

Photos were taken in Oct. 2016

Conclusion

- The shear strength **deterioration of CWS** is **significant**, and the deterioration process is obtained by back-analysis.
- **Active design** method is recommended for CWS slope. IF active design is adopted, the slope **WOULD NOT FAIL**.
- Initial design had caused the slope failure. Remedial measures has to be taken to stabilize the slope.

If we have enough time