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

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Dec. 16, 2016
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.
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

- Natural properties
  - Natural slope
- Disturbed properties
  - excavated slope
- Residual properties
  - Failed slope
- Potential deterioration
  - Saturated caused by rain fall infiltration
The deterioration of rock and soil properties

Natural slope

Failed slope

excavated slope

Potential deterioration
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.
Slip surface CWS

Site investigation after the slope failure

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

Sliding body is CWS

CWS

Mudstone

Slip surface
The strength deterioration process is obtained by back-analysis using limit equilibrium method (LEM).

4 stages are considered:

- natural slope, shear strength $C_1, \phi_1$
- excavated slope, shear strength $C_2, \phi_2$
- failed slope, shear strength $C_3, \phi_3$
- Potential deterioration shear strength $C_4, \phi_4$
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

Shear strength
$C_1=33\text{kPa}, \phi_1=24^\circ$

consistent with natural slope stability state
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  $C_2 = 25 \text{kPa}, \phi_2 = 23^\circ$
CWS shear strength deterioration process

- Failed slope-residual properties

According to site investigation, the slope was still in creep deformation after the slope failure.

Failed slip surface
Fs=1.05

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

\[ C_4 = 21 \text{kPa}, \phi_4 = 10^\circ \]
CWS shear strength deterioration process

- Natural Strength used in Initial design
- Disturbed strength caused SLOPE FAILURE

- $c$ (kPa)
- $\varphi$ ($^\circ$)

Natural slope, disturbed slope, after slope failure, potential deterioration
Active design of the slope

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

If active design method was adopted, the inherent shear strength of CWS will be maintained, the initial design will keep the slope stable.
Remedial measures

- The failed slope was re-designed according to the deteriorated shear strength of CWS.
- The recommended shear strength of CWS is $C_4=21\text{kPa}, \phi_4=10^\circ$.
- 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

- 20m long Anti-sliding piles
- 30m long Anchors
- Drainage
- Slope re-excavated
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