WEATHERING INFLUENCE ON ENGINEERING STRUCTURES

ROBERT HACK
FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION (ITC), UNIVERSITY OF TWENTE,
THE NETHERLANDS.

PHONE: +31 (0)6 24505442; EMAIL: HACK@ITC.NL

ITC, The Netherlands; 30 October 2012
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Robert Hack
Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, Enschede, The Netherlands, hack@itc.nl

ABSTRACT
An overview is given of the influence of weathering on engineering structures in and on natural materials. Some recently developed new ideas to incorporate weathering in design are discussed. All natural materials near and sometimes also deeper below surface of the Earth are subject to weathering. Notoriously difficult to forecast is the geotechnical behaviour due to future deterioration of the ground mass under influence of weathering. Weathering is a strongly local feature influenced by local circumstances such as local climate and weather, groundwater, and humans. Calculation methods and parameters used in design of engineering structures often do not properly anticipate the degradation of natural materials due to weathering. Preliminary failure, i.e. failure of the engineering structure before the end of the planned lifetime, may be the consequence. Slopes and tunnels start to raffle or may fail completely, and even buried foundations may be affected.
what is weathering in engineering
implications for engineering
forecasting weathering
weathering rate
WEATHERING

- Physical, chemical, and biological alteration of rock and soil over time;

- Influenced by the atmosphere and the hydrosphere, and

- Cause rock or soil material to fall apart into smaller pieces or to dissolve in water.
STRESS RELIEF

Due to change in stress field (orientation or magnitude) discontinuities may form or existing discontinuities may open

(discontinuities are bedding planes, joints, fractures, etc.)
WEATHERING & STRESS RELIEF

Difference between effects of weathering and stress relief difficult to distinguish:

Therefore in engineering taken together as being “weathering”
EFFECTS OF WEATHERING

- weakening of intact rock blocks and soil grains
- integral become mechanical discontinuities (i.e. bedding planes not being yet a mechanical plane of weakness become a mechanical plane of weakness)
- material between rock blocks becomes weaker (remains of weathered material)
WHAT GIVES ROCK AND SOIL MASSES STRENGTH

Rock and soil masses consist of:

- intact blocks (rock) with discontinuities in-between (e.g. bedding planes, joints, fractures, etc)
- grains (in soil) with grain contacts in-between

Strength of a mass is given by:

- strength (shear & tensile) of intact rock blocks or soil grains
- shear strength between blocks (rock) or grains (soil)
ENGINEERING EFFECTS

- weaker rock blocks and soil grains
- smaller rock blocks and grains
- shear strength between blocks and grains less
reduction intact rock strength due to solution of cement (gypsum)

1997
slope dip: ≈ 70°

(power: De Boer, 1997)

layers of gypsum cemented clay and silt

2008
slope dip: ≈ 55°

(photo: Hack, 2008-04-12)

Middle Muschelkalk near Vandellos (Spain)

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reduction intact rock strength due to solution of cement (2)

blocks falling from disintegrating wall

Children playground made around 1995
Vandellos, Spain (photos: Hack, 2002)
REDUCTION BLOCK SIZE

SAME MATERIAL
THE MORE EXPOSED
THE SMALLER THE BLOCK SIZE
CINDARTO SLOPE:
VARIATION IN CLAY CONTENT 
IN INTACT ROCK CAUSES 
DIFFERENTIAL WEATHERING

shear strength reduction between blocks and grains (1)

bedding planes

April 1990

Slightly higher clay content on bedding plane
shear strength reduction between blocks and grains (2)

CINDARTO SLOPE VARIATION IN CLAY CONTENT IN INTACT ROCK CAUSES DIFFERENTIAL WEATHERING

April 1992

mass slid
shear strength reduction between blocks and grains (3)

carbonate is dissolved at bedding plane – clay remains
Degrees of weathering

- Fresh
- Moderately
- Slightly
- Highly
- Residual soil
- Completely

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IMPACT OF WEATHERING


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WEATHERING IN TIME

weathering rate depends on:

- local climate & weather (e.g. wind direction)
- groundwater
- land-use (fertilizer)
- does it stay exposed or is it covered by weathered material (erosion)
- method of excavation
WEATHERING & TIME

Weathering based on rock & soil dissolution back analyses:

| Rate [mm/y] | 
|-------------|------------------|
| **average world** | 0.006 |
| **cold climate** | < 0.001 (Olvmо, 2010) |
| **warmer climate** | > 0.1 |
| **tropics metamorphic rock mass** | 0.04 Brazil (Moreira-Nordemann, 1980) |
| **tropics silica rock mass** | 0.058 Puerto Rico (White et al., 1998) |
| **mountainous areas with high erosion rates** | mm's |
WEATHERING & TIME

- Dissolution in 50 years thus around $\frac{1}{2}$ to 5 mm
- Dissolution in particular around discontinuities
- Dissolution in the order of fraction of mm
- Fraction of mm enough to reduce (shear) strength

Hence, even in relative short time spans of 50 to 100 years, weathering may have a substantial negative influence on properties of soil and rock masses.
- Cleopatra’s needle
  Central Park, New York
INFLUENCE WEATHERING ON DESIGN

excavated slope

present “naturally” formed slope

shale
dolomite
dolomite
shale
dolomite
shale
dolomite

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Poor blasting of slope caused increased permeability and consequently allowed for loss of structure and rapid weathering of thin clay inter-bedded softer layers.
POORLY BLASTED SLOPE

- 1990: new cut: slope height 13.8 m high, dip 70°
- 2002: slope dip about 55°
- 2005: slope dip about 52°
- SSPC forecast final stability: slope dip about 45°

(SSPC after Hack et al, 2003)
Diabase (subvolcanic rock equivalent to volcanic basalt)
made in: 1995
photos: 2011

Silver Creek Cliff Tunnel, Route 61, Duluth, MN, USA

Road protection wall built in 2010 to prevent stones on the road

BLASTING DAMAGE CAUSES RAPID RAVELLING AND LOSS OF STRUCTURE AND CONSEQUENTLY WEATHERING
Fine grained calcareous mudstone falling apart within a couple of years after excavation.

South Korea

(photos Hack, 2008)
Future Degradation

Reduction in slope angle due to weathering, erosion and ravelling (after Huisman et al, 2006)
FUTURE DEGRADATION

Main processes involved in degradation:

- Loss of structure due to stress release
- **Weathering** (In-situ change by inside or outside influences)
- **Erosion** (Material transport with no chemical or structural changes)
WEATHERING RATE

- The susceptibility to weathering is a concept that is frequently addressed by “the” weathering rate of a rock material or mass.
- Weathering rates may be expected to decrease with time, as the state of the rock mass becomes more and more in equilibrium with its surroundings.
\[ WE(t) = WE_{init} - R_{WE}^{app} \log(1 + t) \]

*WE(t)* = degree of weathering at time *t*

*WE*\(_{init}\) = (initial) degree of weathering at time *t* = 0

*R*\(_{WE}^{app}\) = weathering intensity rate

**WE as function of time, initial weathering and the weathering intensity rate**
GYPSUM CLAYSTONE SLOPE IN VANDELLOS

SSPC system with applying weathering intensity rate:
- original slope cut about $50^\circ$ (1998)
- in 15 years decrease to $35^\circ$
KOTA KINABALU, MALAYSIA

10 years old

5 years old

(after Tating, Hack, & Jetten, 2011)
KOTA KINABALU

Side road (dip 45°, 5 years old)
sandstone: slightly weathered

SSPC
stability:
Sandstone:
stable (92%)
Shale:
unstable (< 5%)

(after Tating et al., 2012)
KOTA KINABALU

Main road (dip 30°, 10 years old):
sandstone: moderately weathered
SSPC
stability:
Sandstone: stable (95%)
Shale: ravelling (<5%)

(after Tating et al., 2012)
KOTA KINABALU

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SSPC system in combination with degradation forecasts gives:

- reasonable design for slope stability
- with minimum of work and
- in a short time
- (likely a reasonable tool to forecast susceptibility to weathering)
REFERENCES