CHARACTERIZATION AND MONITORING OF SLOPES (27)

I Main Topics
- B Reconnaissance
- C Aerial imagery
- D Engineering geologic mapping
- E Ground deformation surveys
- F Boreholes and piezometers

II Reconnaissance

A Obtain and review existing literature*
- 1 Reports and journal publications
- 2 Maps (e.g., geologic, topographic, soil, lot line)

B Review beyond immediate site limits*

C Obtain and review aerial imagery of site (ideally for different years or different seasons)*

D Visit the site and perform field reconnaissance*

E Repeat steps A-D as necessary

F Decide where more detailed information is required

* Note: Order steps A-D as appropriate

III Aerial imagery

A Aerial photography

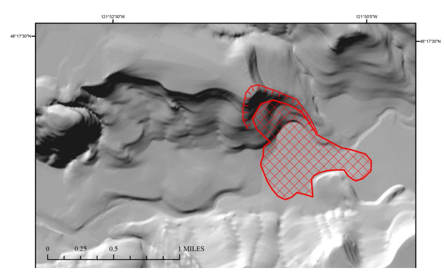
1 Effective, relatively low cost
2 Sun angle (high vs. low)
3 Vertical vs. oblique
4 Slope moisture and vegetation vary seasonally
5 Fine-grained, low-permeability surficial materials commonly have fine-grained drainage patterns
6 Moist slopes often appear darker than light slopes
7 Pay attention to vegetation
8 Color bests black and white

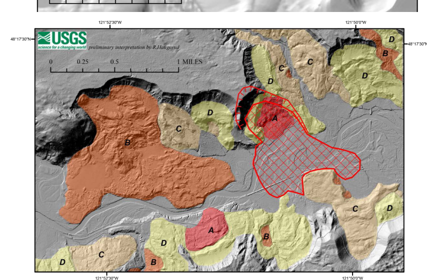
http://earthobservatory.nasa.gov/blogs/earthmatters/2014/03/26/aerial-views-of-the-landslide-in-oso-washington/

III Aerial imagery

B LIDAR

1 Near-photographic resolution
2 Good map base
3 Provides DEM
4 Can analyze digitally
5 Can digitally remove vegetation
6 Can chose direction of synthetic illumination and perspective

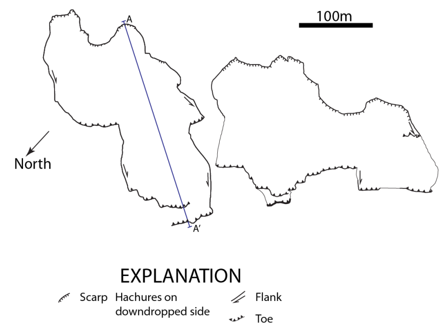




IV Engineering Geologic Mapping

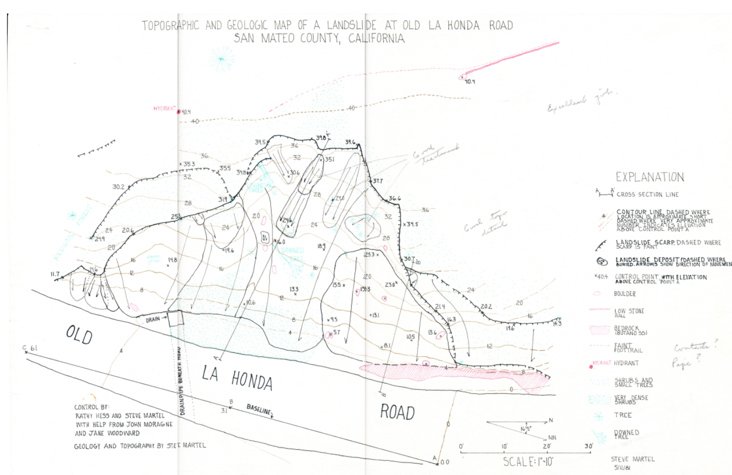
- A Large-scale, site-specific geologic maps of engineering relevance
- B Map features
  1. Slide boundary/boundaries
  2. Geomorphic features (e.g., landslide boundaries)
  3. Type of rock or soil units
  4. Bedding attitudes
  5. Geologic structures
  6. Topography/slope
  7. Fractures and faults
  8. Water sources, seeps, and channels
  9. Displacements
  10. Property boundaries
  11. Relevant vegetation
  12. Locations of cross sections

Map of the borders of two landslides



Modified from Baum and Fleming, 1991

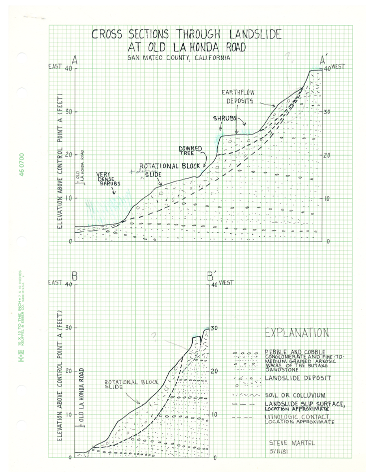
IV Engineering Geologic Mapping Example



IV Engineering Geologic Mapping

C Engineering geologic/ topographic profile

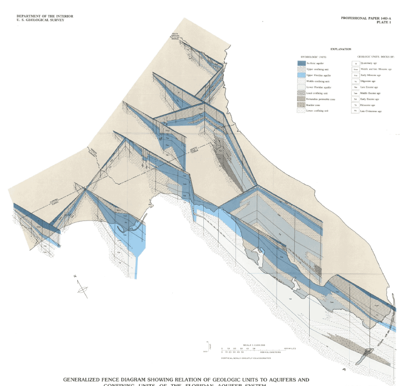
1. Establish control points
2. Map relevant features
3. Project features to depth



3/20/15 GG454 7

IV Engineering Geologic Mapping

D Fence diagram (useful for large, complicated slides)



http://sofia.usgs.gov/publications/papers/pp1403a/plates/plate1-lg.gif

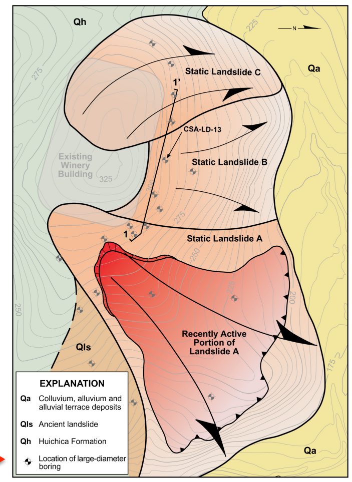
3/20/15 GG454 8

IV Engineering Geologic Mapping

E Useful for siting boreholes, trenches, geophysical surveys, inclinometers, and piezometers

F Update maps and cross-sections based on boreholes, trenches, geophysical surveys, inclinometers, and piezometers

G Monitor holes

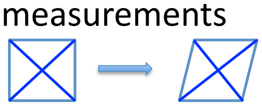


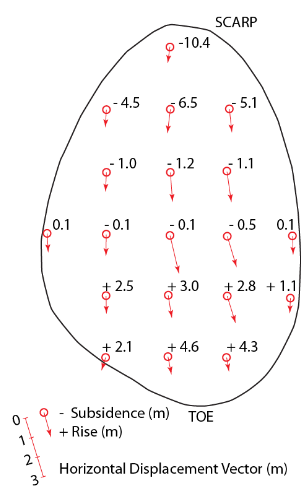
3/20/15 GG454 9

V Ground deformation surveys

A Establish survey points for monitoring slide; some must extend beyond the landslide to stable points

B Survey the diagonals between grid points for quadrilateral strain measurements





3/20/15 GG454 10

V Ground deformation surveys

C Evaluate displacement and strain (from triangular elements; see strain rosette problem of Middleton and Wilcock, 1994, p. 253-254)

1 Displacements from changes in position
2 Principal strains from changes in lengths (extensions) of legs of triangles in survey

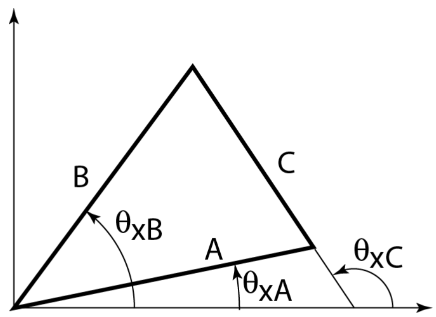
$$\varepsilon_A = \varepsilon_{xx}\cos^2\theta_{xA} + \varepsilon_{xy}\sin 2\theta_{xA} + \varepsilon_{yy}\sin^2\theta_{xA}$$
$$\varepsilon_B = \varepsilon_{xx}\cos^2\theta_{xB} + \varepsilon_{xy}\sin 2\theta_{xB} + \varepsilon_{yy}\sin^2\theta_{xB}$$
$$\varepsilon_C = \varepsilon_{xx}\cos^2\theta_{xC} + \varepsilon_{xy}\sin 2\theta_{xC} + \varepsilon_{yy}\sin^2\theta_{xC}$$

$$\begin{bmatrix}\varepsilon_A\\ \varepsilon_B\\ \varepsilon_C\end{bmatrix} = \begin{bmatrix}\cos^2\theta_{xA} & \sin 2\theta_{xA} & \sin^2\theta_{xA}\\ \cos^2\theta_{xB} & \sin 2\theta_{xB} & \sin^2\theta_{xB}\\ \cos^2\theta_{xC} & \sin 2\theta_{xC} & \sin^2\theta_{xC}\end{bmatrix}\begin{bmatrix}\varepsilon_{xx}\\ \varepsilon_{xy}\\ \varepsilon_{yy}\end{bmatrix}$$

$$[\varepsilon^*] = [A][\varepsilon]$$

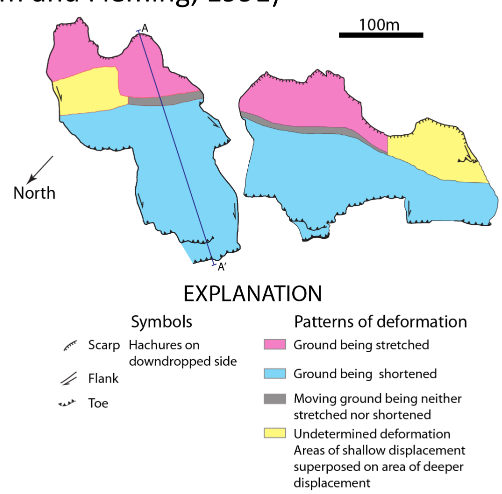
$$[A^{-1}][\varepsilon^*] = [\varepsilon] \Rightarrow \begin{bmatrix}\varepsilon_{xx} & \varepsilon_{xy}\\ \varepsilon_{xy} & \varepsilon_{yy}\end{bmatrix} = \begin{bmatrix}\varepsilon_{xx} & \varepsilon_{xy}\\ \varepsilon_{yx} & \varepsilon_{yy}\end{bmatrix} \Rightarrow \begin{bmatrix}\varepsilon_1 & 0\\ 0 & \varepsilon_2\end{bmatrix}$$

Symmetric strain matrix — Principal values



V Ground deformation surveys

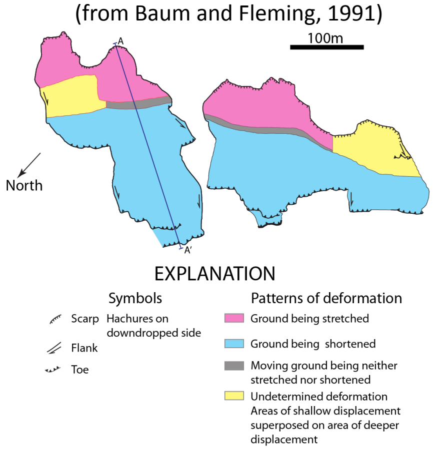
D Example of map of strain on the surface of a landslide (from Baum and Fleming, 1991)

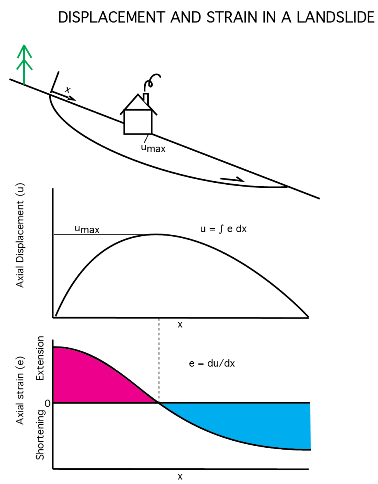


V Ground deformation surveys

E Strain measurement vs. theoretical predication

Map of strain at the surface of a landslide (from Baum and Fleming, 1991)





VI Boreholes and piezometers

A Small (<10 cm diameter) boreholes
1. Useful for directly detecting features at depth
2. Drilling alters sample properties and water content; this can compromise value of lab tests using extracted samples
3. Boreholes sample a statistically insignificant part of a body. Need to use judgment as to how far to extrapolate drilling data, how many holes to drill, and where to drill them; <u>this is a very persistent problem in geotechnical practice</u>.
4. Vertical boreholes tend to miss vertical fractures

VI Boreholes and piezometers

B Large-diameter (~0.5m) boreholes

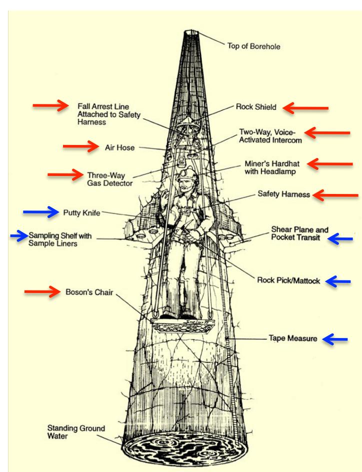
1 Geologist entering a borehole in an aluminum logging cage.

From Johnson and Cole, 2001

VI Boreholes and piezometers

B Large-diameter (~0.5m) boreholes

2 Diagram showing equipment for safety and logging in a large borehole

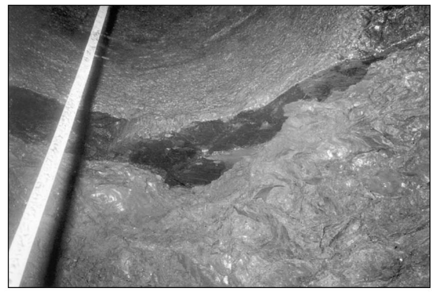


From Johnson and Cole, 2001

VI Boreholes and piezometers

B Large-diameter (~0.5m) boreholes

3 Photograph looking upward at gouge materials exposed below a polished bounding surface within a large-diameter borehole.



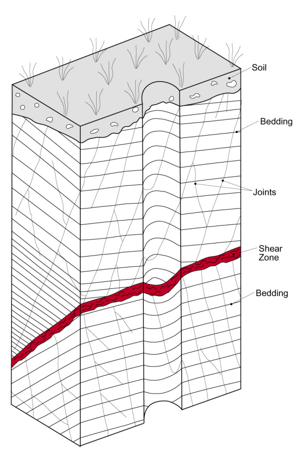
From Johnson and Cole, 2001

VI Boreholes and piezometers

B Large-diameter (~0.5m) boreholes

5 Diagram showing planar structural elements (bedding, joints and a shear zone) intersecting a hypothetical borehole and cross section.

6 The attitude of the planar elements can be solved for with three points on the borehole trace.

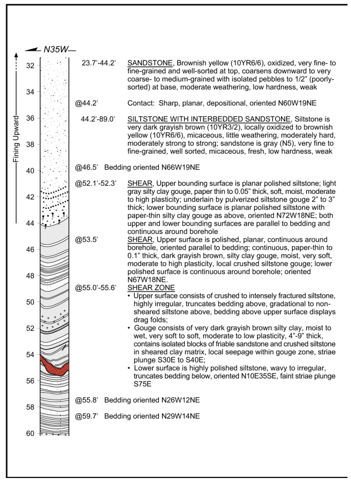


From Johnson and Cole, 2001

VI Boreholes and piezometers

B Large-diameter (~0.5m) boreholes

6 Example of a downhole log describing lithologic units, layering, shears, and orientation of bedding.



From Johnson and Cole, 2001

VI Boreholes and piezometers

B Large-diameter (~0.5m) boreholes

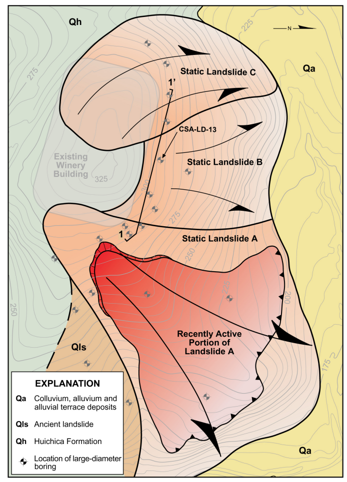
5 Photograph of shear zone samples. In this case, brass sample liners were driven into gouge materials that overlie a striated bounding surface.

From Johnson and Cole, 2001

VI Boreholes and piezometers

B Large-diameter (~0.5m) boreholes

7 Simplified map of the Napa winery site showing the location of static and recently active landslides, large-diameter borings and the existing winery building

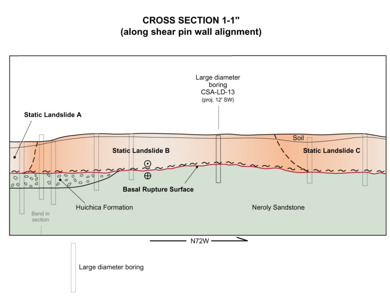


From Johnson and Cole, 2001

VI Boreholes and piezometers

B Large-diameter (~0.5m) boreholes

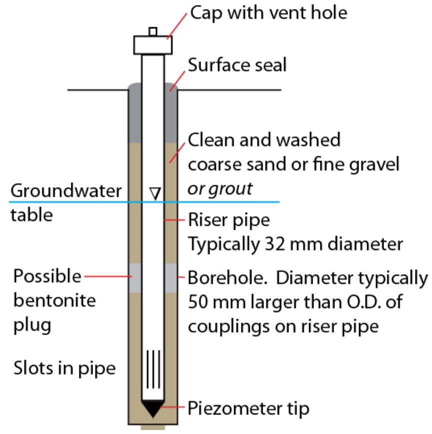
8 simplified cross section along the alignment of the series of large-diameter borings drilled at the Napa winery site. This cross section is based upon data from a series of large-diameter borings within landslides B and C.



From Johnson and Cole, 2001

VI Boreholes and piezometers

C Piezometers (for evaluating water head)
   1 Piezometers commonly are inexpensive and very useful
   2 Displacement and water table level commonly coupled (Iverson and Major, 1987)
   3 Values at a point; pose extrapolation challenge
   4 Deformation during sliding (e.g., cracking) can radically alter the hydrology of a slide (Harp et al., 1990)
   5 Piezometer holes can change the hydrology of a slide



Modified from http://www.fhwa.dot.gov/bridge/tunnel/pubs/nhi09010/15a.cfm

3/20/15 GG454 23

References

- http://www.geoinsite.com/images/GeoinsiteData2/johnson_and_cole_2001_downhole_logging.pdf
- Middleton, G.V., and Wilcock, P.R., 1994, Mechanics in the earth and environmental sciences, Cambridge University Press, London, 476 p.
- Iverson, R.M., and Major, J.J., 1987, Rainfall, groundwater flow, and seasonal movement at Minor Creek landslide, northwestern California: Physical interpretation of empirical relations: Geological Society of America Bulletin, v. 99, p. 579-594.
- Harp, E.W., Wells, W.G., Sarmiento, J.G., 1990. Pore pressure response during failure in soils. Geological Society of America Bulletin, v. 102, p. 428–438.

3/20/15 GG454 24