Technical Note

Engineering Stratigraphic Columns

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Key Terms: *Stratigraphic Column, Engineering Properties, Hazards, Mapping*

INTRODUCTION

A dilemma in engineering geologic mapping is how to provide the greatest amount of useful information in the smallest space and in the most visually logical format. Stratigraphic columns, traditionally used to show strictly geologic information, may be adopted to address engineering and hazard identification concerns. Columns can be constructed to show fracture density, rock mass rating, resistance to weathering, soil development, water flow, and other useful parameters for rock cuts, tunnels, foundations, and aggregate potential. Each column summarizes the anticipated engineering behavior of a given vertical section of the local bedrock, and this behavior may be extrapolated, with due care, to other locales where the same section of rock is present.

We have used engineering stratigraphic columns for several years as teaching tools (Santi and Gregg, 1999), but they can also serve as concise local or regional reference tools for engineering geologists, much as traditional geologists reference standard stratigraphic columns.

EXAMPLES OF PREVIOUS WORK

Standard stratigraphic columns typically correlate the width of the column to the grain size of each unit, as shown on the example in Figure 1a, or to the resistance to weathering of each unit. A variety of geologic, sedimentological, and genetic information may be displayed, including bedding, nodules, minor mineralogical components, fossils, bioturbation, and other sedimentary structures. If included, the descriptive text adjacent to the column usually details formation name; lithology; range in formation thickness; rock type; minor beds; and information on fossils, color, and sedimentary structures. Standard columns emphasize vertical changes in the rock sequence, at the expense of recognizing lateral variations (Tucker, 1996). They also focus on rock descriptions and ignore soil units.

Very little work has been done on the use of stratigraphic columns to portray engineering information. The closest analogy to engineering stratigraphic columns is the portrayal of engineering information on wall or trench logs. For instance, Figure 2, from Dearman (1991), shows an exposure log that displays several useful engineering properties, including weathering grade, fracture spacing, point load strength, and likely excavation conditions.

ENGINEERING STRATIGRAPHIC COLUMN CONSTRUCTION

The purpose of an engineering stratigraphic column is to readily assess the engineering properties of a vertical section of rock. The columns integrate the engineering information available from a bore hole with the advantages of the two- or three-dimensional view available in an outcrop. A single complete column can be used to provide engineering information for a large region, similar to a geologic stratigraphic column, which often represents areas up to thousands of square kilometers. Specifically, an engineering stratigraphic column can be used to depict:

- Slope stability and expected modes of rock slope failure
- Water flow or contaminant transport along various bedding contacts
- The quality of rock and soil materials for aggregate or fill
- The strength of rock units and the soils developed on top of them
- The thickness and continuity of soil units

Table 1 contains a list of the suggested symbols for use with engineering stratigraphic columns, and Figure 1b is an example column that represents the contact region between the Ordovician Roubidoux Sandstone and Gasconade Dolomite in central Missouri. This is the same section of rock shown as a geologic column in

Figure 1. (a) Example stratigraphic column of the Roubidoux Sandstone–Gasconade Dolomite contact near Rolla, MO (prepared by the authors). (b) Example engineering stratigraphic column.

Figure 2. Example of logging of rock face for engineering purposes (from Dearman, 1991).

Figure 1a. Although we suggest that users construct a key to accompany each column, the symbols were designed to be as intuitive as possible so that the key will not be crucial to interpreting or understanding the column. A tremendous range of engineering properties may be shown using the symbols in Table 1, and a discussion of the mapping and significance of each property is presented later in this article. The method is not a substitute for engineering judgment and experience, but rather a shorthand method to visually display the mapper's conclusions.

Groundwater flow is noted on the engineering stratigraphic column by a standard spring symbol used for topographic maps. The symbol is open to represent very low flow, half filled to represent steady moderate flow, and completely filled to represent high flow. This information, coupled with vegetation information, will indicate water transport zones.

Engineering Stratigraphic Columns

Table 1. Suggested symbols for engineering stratigraphic columns.

Property	Symbol	Explanation			
Water flow		trace / drip / moist ground			
		low steady flow (< 4 liters per minute / <1 gpm)			
		high steady flow (> 4 liters per minute / >1 gpm)			
Vegetation (fed by seepage)		grass			
		shrubs / trees			
Susceptibility to rockfall			ravelling of small blocks < 1/3 m (1') diam.	failures of large, intact blocks > 1/3 m (1') diam.	accumulation of >1 m³ talus for every 5 horizontal m of outcrop
		high	✓	✓	✓
		moderate	✓	--	✓
		low	✓	--	--
		none	--	--	--
Rock		width corresponds to strength			
Natural cliff former					
Natural slope former		maximum width corresponds to strength of unweathered rock			
Soil		width corresponds to strength height corresponds to thickness			
Continuous soil or weathered unit					
Discontinuous soil unit or slopewash		width corresponds to strength height corresponds to thickness unit is placed within bed from which it forms			
Discontinuity orientation and spacing	spacing	up and out of slope	vertical	up and into slope	horizontal / bedding
	>1m (>3')	//		\\	=
	1/3-1m (1-3')	///		\\\	≡
	<1/3m (<1')	////		\\	≡
Interstitial permeability (response to drops of water on rock surface)	V. Low K	<10 ⁻⁷ cm/sec	most of the water remains on the surface		
	Low K	10 ⁻⁵ – 10 ⁻⁷ cm/sec	some water is absorbed		
	Mod. K	10 ⁻³ – 10 ⁻⁵ cm/sec	more than half the water is absorbed		
	High K	>10 ⁻³ cm/sec	most of the water is absorbed		
Weathering grade	F	Fresh. No visible sign of decomposition or discoloration. Rings when struck by hammer.			
	WS	Slightly Weathered. Slight discoloration inwards from open fractures, otherwise similar to F.			
	WM	Moderately Weathered. Discoloration throughout. Weaker minerals such as feldspar decomposed. Strength < fresh rock but pieces cannot be broken by hand or scraped by knife. Texture preserved.			
	WH	Highly Weathered. Most minerals somewhat decomposed. Specimens can be broken by hand with effort or shaved with knife. Corestones present. Texture becoming indistinct but fabric preserved.			
	WC	Completely Weathered. Minerals decomposed to soil but fabric and structure preserved (saprolite). Specimens easily crumbled or penetrated.			
	RS	Residual Soil. Advanced state of decomposition resulting in plastic soils. Rock fabric and structure completely destroyed. Large volume change.			
Rock Mass Rating	RMR	Depends on intact rock strength, RQD, discontinuity spacing and conditions, and ground water (refer to Bieniawski, 1989 for details). 81-100 = very good rock 21-40 = poor rock 61-80 = good rock < 20 = very poor rock 41-60 = fair rock			
Soil and Rock Type		Use standard symbols.			

Table 2. *Field estimation of rock and soil strength (from Anonymous, 1997).*

Field Estimation	Unconfined Compressive Strength (MPa)
Soil extrudes between fingers when squeezed in hand	<0.04
Soil is easily molded with fingers	0.04–0.08
Soil can only be molded by strong pressure of fingers	0.08–0.15
Soil cannot be molded by fingers	0.15–0.30
Soil can be indented by fingernail	0.30–0.60
Brittle or tough, may be broken by hand with difficulty	0.60–1.25
Very soft rock; material crumbles under firm blows with sharp end of a geological pick	1.25–5.0
Too hard to cut by hand into a cylindrical lab specimen	5.0–12.5
Soft rock, 5-mm indentations with sharp end of a rock pick	12.5–50
Hard rock, handheld specimen can be broken with single blow of a geological hammer	50–100
Very hard rock; more than one blow of a geological hammer required to break specimen	>100

Susceptibility to rock fall is represented by symbols of small rocks placed near the edge of each outcrop layer. Three rocks implies a high rock-fall volume and frequency, two implies moderate volume and frequency, one implies low volume and frequency, and the absence of the symbol indicates that no rock-fall potential was noted in the field. A standardized system to assess the degree of susceptibility is presented in Table 1. As shown, the level of the susceptibility may be quickly assessed by estimating the size of the blocks that have fallen from a given stratum along with the volume of material that has accumulated below the stratum. This system may present difficulties where no direct catchment area is present below a stratum. Therefore, the user must make estimates of failure types and volumes based on fresh scars from recent failures on the rock face, identification of rock fall from the stratum in question as float rock at the base of the outcrop, and assessment of the expected behavior of a stratum based on fracture condition and density.

Expected slope stability can also be gauged by the natural slope angle of a rock unit: many units are known regionally as 'slope formers' or 'cliff formers.' An approximation of the slope angle can be used on the stratigraphic column, as shown in Table 1. In each case, the maximum width of the column corresponds to the strength of unweathered rock, using a strength scale at the base of the column drawing. A Schmidt Type-L Hammer works well to measure rock strength in the field, and a pocket penetrometer can be used for soil strength. As an alternative, Table 2 summarizes a method of estimating soil and rock strength in the field. If the measured or estimated rock strength exceeds 100 MPa, the right-hand edge of the column may be drawn as a straight (not ragged) vertical line at 100 MPa.

The strength and thickness of soil units, slope wash, or paleosols are displayed in a similar manner as rock units, where the width and height represent the strength and thickness, respectively. If a soil unit between two rock layers is expected to continue at depth into the

outcrop, the unit is shown on the column as a continuous layer separating the two rock units. This situation may occur if the soil is an easily weathered layer that has been broken down by water transport along the contact. If a soil unit is not expected to continue at depth, as would be the case for slope wash or for a shallow weathered pocket in the rock face, the unit is mapped within its parent rock unit. Soil information may also be obtained from locations away from the outcrop being mapped, because representative soils associated with a given rock unit may be fully developed only where that unit is at the top of the outcrop.

Discontinuity spacing and general orientation are shown by sets of short lines with similar orientation. Increasing numbers of lines indicate closer discontinuity spacing and lower expected slope stability. Lines slanted upward and out of the slope indicate a propensity for toppling or raveling failures; vertical lines indicate possible slab failures; and lines slanted upward and into the slope indicate possible sliding or wedge failures. Bedding planes may also be shown; in this example they are shown as horizontal lines. The strike and dip of major discontinuity sets may be typed on the column as well.

Interstitial permeability of rock and soil units may be estimated using the method proposed by Lee and De Freitas (1989), where several drops of water are placed on the rock surface and the degree of absorption is estimated. As indicated in Table 1, high water absorption is an indication of high rock permeability.

Weathering grade categories are those proposed by Dearman and others (1978). We suggest that the user apply these categories to rock material below any thin, weathered rind on the rock surface, which does not accurately represent the properties of the rock mass.

Rock Mass Rating (RMR) is the rock mass classification system proposed by Bieniawski (1976). Although any of several rock mass classification schemes may be used, this one has the dual advantages of popularity and potential application to slopes, foundations, and tunnels.

Symbols representing soil and rock types should be

standardized, similar to those used in geologic stratigraphic columns and soil boring logs.

Once completed, the engineering stratigraphic column summarizes the anticipated engineering behavior of a given vertical section of the local bedrock, and this behavior may be extrapolated, with due care, to other locations where the same section of rock is present. A summary of the engineering information that may be inferred from the column shown in Figure 1 is as follows:

- Water flow is concentrated along the Roubidoux–Gasconade contact at 3.7 m. Water also flows within the weaker dolomite layers at 3 m and 2 m.
- Because of vertical fracturing and horizontal bedding, the rock is stable in vertical cuts except for the slope-forming units from 2 to 3.7 m. There is evidence of rock fall from small topples and from raveling, which is more pronounced in the dolomite.
- Except for the weak Upper Gasconade, the rock units are strong and classify as ‘good rock’ by the RMR system. Depending on specific joint orientations, the rock is expected to serve well in foundations, road cuts, and tunnels, and it is expected to be a durable aggregate.
- Soil units are thin and discontinuous and represent slope wash within the section. The soil at the top of the section is also thin and probably residual in origin.

CONCLUSIONS

Stratigraphic columns may be prepared in such a way as to improve our ability to combine geologic and engi-

neering information and display it in a visual format that is easy to interpret and assimilate. They can demonstrate regional rock quality, stability, weathering characteristics, and water flow. Each column summarizes the anticipated engineering behavior of a given vertical section of the local bedrock, and this behavior may be extrapolated, with due care, to other locales where the same section of rock is present.

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