Correlation Between V_S and RQD for Different Rock Types

Emre Biringen
Bechtel Power Corporation, Frederick, MD

John Davie
Bechtel Power Corporation, Frederick, MD

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CORRELATION BETWEEN V_S AND RQD FOR DIFFERENT ROCK TYPES

Emre Biringen
Senior Geotechnical Engineer
Bechtel Power Corporation
Frederick, Maryland, USA
ebiringe@bechtel.com

John Davie
Senior Principal Engineer
Bechtel Power Corporation
Frederick, Maryland, USA
jdavie@bechtel.com

ABSTRACT

Although there is no direct relationship between the shear wave velocity (V_S) of in-situ rock and Rock Quality Designation (RQD), it is apparent that some relationship exists since both V_S and RQD decrease in fractured and weathered rock. However, unweathered or unfractured soft rock will have comparatively low V_S compared with unweathered or unfractured hard rock since V_S is a function of rock hardness and density. Thus, any relationship between V_S and RQD will be specific to a particular rock type, and, in many cases, to a particular area/region where the hardness and density of a specific rock type varies significantly with location. This paper examines the relationship between V_S and RQD for three different rock types located in Virginia, South Carolina and Florida. The Virginia rock is strong metamorphic (gneiss), the South Carolina rock is strong igneous (granodiorite), and the Florida rock is moderately weak to strong sedimentary (limestone). High quality H- and P-size rock cores were taken in multiple borings at each site and RQD for each core was recorded. Rock thickness ranged from about 90 ft to over 300 ft. V_S was measured in each boring at 1.64-ft intervals using P-S Suspension logging. Correlation between V_S and RQD was computed for each site using all of the recorded data. Reasonable correlations were achieved at the two hard rock sites, although the relationships were predictably different. The relationships at the two hard rock sites being closer compared to that at the weaker rock site. At each of the three sites, only a small fraction of the borings made had V_S measurements. In the remaining borings, the relationships derived for V_S versus RQD could be used to obtain an approximate V_S profile using the RQD measurements.

INTRODUCTION

For licensing new generation nuclear power plants, geophysical techniques with shear wave velocity measurements (i.e., downhole suspension P-S velocity logging) have been used as the main source for rock mass characterization. The differentiation between fractured or weathered rock and the more competent rock is commonly made based on Rock Quality Designation (RQD) ranges of the rock samples cored and/or based on shear wave velocity measurements. However, in the cases where shear wave velocity measurement is limited, the interpretation heavily relies on RQD. This paper examines the relationship between shear wave velocity and RQD for three rock sites in the USA and establishes approximate correlations, based on the results of subsurface investigations.

Rock Coring

At all three sites, rock coring was performed in general accordance with ASTM D 2113-06 upon SPT or auger refusal. After core removal from the split inner barrel, the onsite geologist visually described the cored rock, noting the presence of joints and fractures, and distinguishing natural breaks from mechanical breaks. RQD was calculated based on the core runs sampled. ASTM D 6032-02 states that for the standard test method for determining RQD of rock core: "The RQD denotes the percentage of intact and sound rock retrieved from a borehole of any orientation. All pieces of intact and sound rock core equal to or greater than 4 inches long are summed and divided by the total length of the core run." The core barrels used during coring were HQ-3 and PQ-3, which produce core diameters of approximately 2.4 to 3.5 inches.

Suspension P-S Velocity Logging

The shear wave (V_S) and compressional wave (V_P) velocities in selected boreholes were measured by downhole suspension P-S velocity logging (also known as suspension logging). Measurements were made at 1.64-ft intervals in boreholes that were uncased and fluid-filled. This system determines the average velocity of 3.3-ft and 6.3-ft high segments of the soil/rock column surrounding the borehole by measuring the elapsed time between arrivals of a wave propagating upward through the soil/rock column. A typical suspension P-S logging system consists of a borehole probe, cable, winch, and control/recording instrument as shown in Figure 1 for the OYO PS 170 system. The probe consists of a source (S) and two biaxial geophones (R1 and R2), separated by flexible isolation sections (GEOVision).

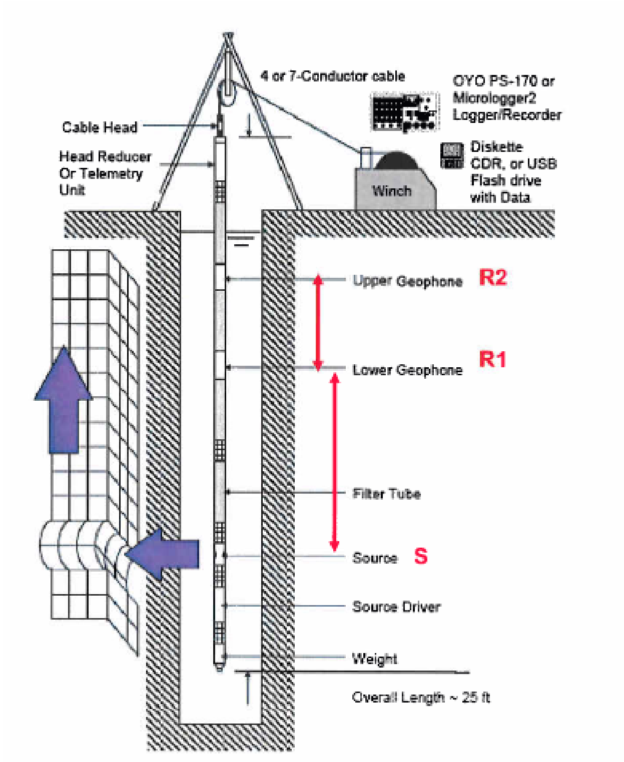

Figure 1. Illustration of P-S logging system (GEOVision)

For each V_S and V_P measurement, there are two sets of data, which are taken (i) between the near and far receivers (R1-R2), and (ii) between the source and near receiver (S-R1). V_S and V_P values are calculated from the travel time (i) over the distance of 3.3 ft between the near and far receivers (R1-R2), and (ii) over the 6.3-ft interval from source to near receiver (S-R1). Since, S-R1 averages a distance two times longer than R1-R2, S-R1 shows a smoother record, and tends to mask true variability. V_S values measured between the near and far receivers (R1-R2) are considered as the appropriate velocity values (Biringen and Davie, 2010). Thus, in this paper, only V_S values measured between the near and far receivers (R1-R2) are presented.

DATA ASSESSMENT

Figure 2 shows the V_S measurements versus depth in rock from one of the boreholes at the South Carolina site along with the RQD values. For each rock core depth interval with an assigned RQD value, the V_S data points that fall inside the boundaries of that depth interval are averaged and displayed as $V_{S\text{-avg}}$ in the same figure. All of the V_S data points are averaged over RQD depth intervals in a similar manner for each borehole. A single $V_{S\text{-avg}}$ value is thus generated for each RQD measurement. The corresponding correlation between RQD and $V_{S\text{-avg}}$ data sets is presented in the following subsections for all three sites.

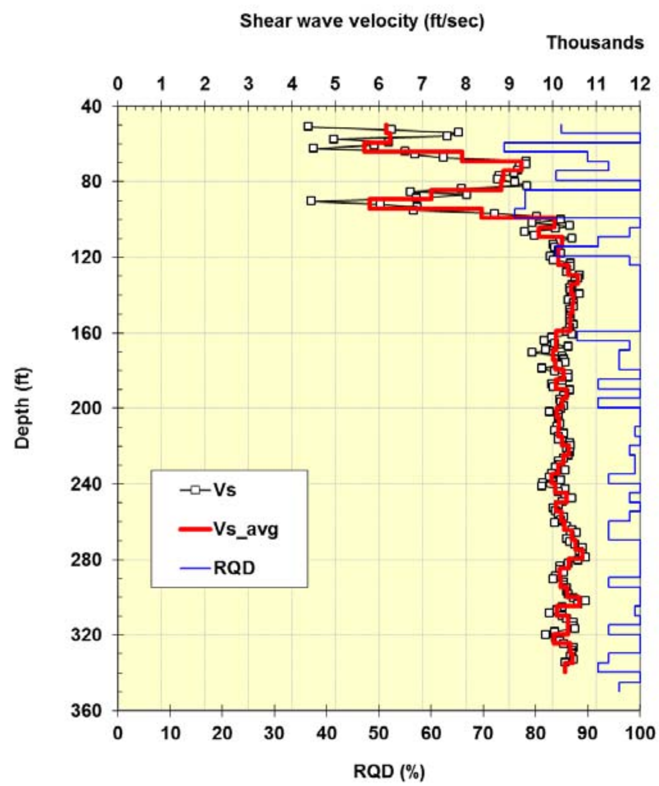

Figure 2. V_S and RQD measurements in igneous rock at the South Carolina site

South Carolina Site

The subsurface investigation describes the bedrock as hard fresh to slightly discolored igneous rock with numerous metamorphic inclusions. The rock consists of mostly granodiorite, quartz diorite, gneiss or migmatite. The upper portion of bedrock is moderately weathered, with more than 50% by volume interspersed with decomposed layers. RQD values obtained from 30 borehole logs were averaged over 5-ft depth intervals. The average RQD of the moderately weathered rock varied between 0% and 60%, whereas the sound rock was generally very hard and intact with an average RQD in the range of 80% to 100%. Based on ASTM D 6032-02, the quality of the sound rock classifies as “good to excellent.” The unit weight of the rock core specimens ranged from 165 to 193 pcf, with an average of 180 pcf.

The depth of the four boreholes in which downhole P-S suspension logging was performed varied from about 175 ft to

350 ft. As noted earlier, for each rock core depth interval with an assigned RQD value, the V_S data points that fall inside the boundaries of that depth interval are averaged. The corresponding correlation between RQD and $V_{S\text{-}avg}$ is shown in Figure 3 for the igneous rock, based on the data from the four deep boreholes.

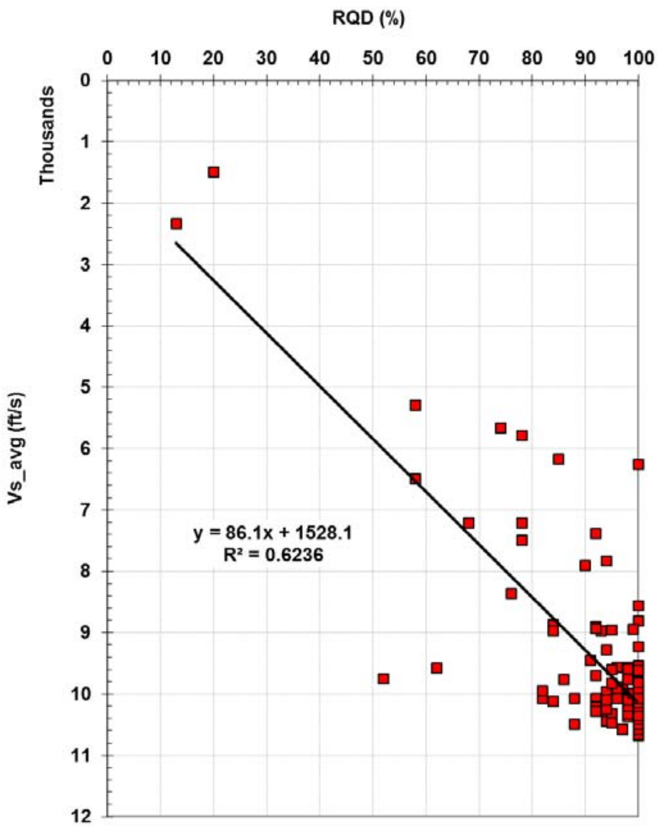

Figure 3. V_S and RQD correlation for igneous rock at the South Carolina site

Virginia Site

The subsurface investigation describes the bedrock as metamorphic rock, mainly gneiss, ranging from quartz gneiss with biotite to biotite granite gneiss, and sometimes biotite hornblende gneiss or quartz gneiss with feldspar or muscovite. The depth of the five boreholes in which downhole P-S suspension logging was performed varied from about 200 ft to 300 ft. The RQD values in sound rock are generally above 80% and mostly above 90%. For the upper weathered rock and the slightly to moderately weathered rock, the RQD ranges from zero to around 50%, and from 50 to 90%, respectively.

For each rock core depth interval with an assigned RQD value, the V_S data points that fall inside the boundaries of that depth interval are averaged, as described earlier. The corresponding correlation between RQD and $V_{S\text{-}avg}$ is shown in Figure 4.

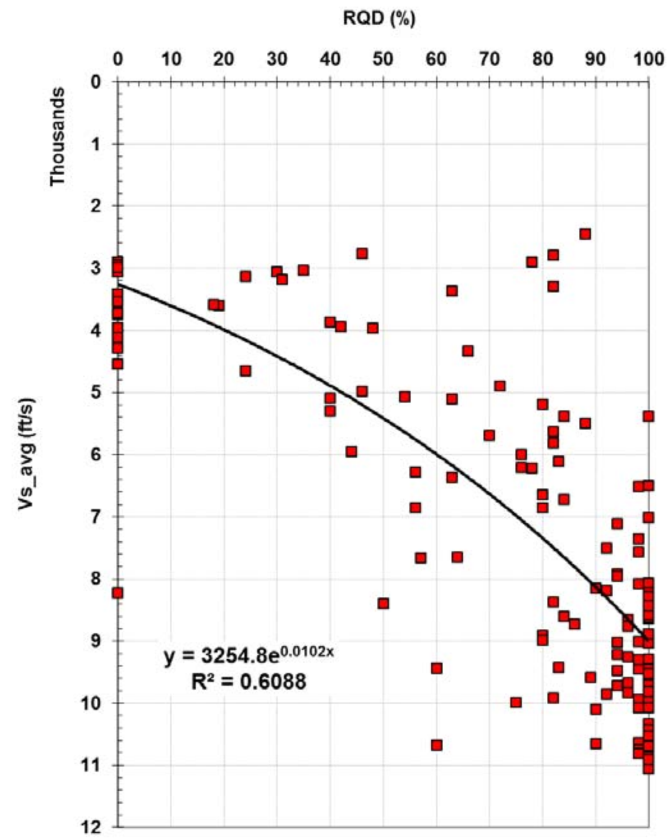

Figure 4. V_S and RQD correlation for metamorphic rock at the Virginia site

Florida Site

The Key Largo formation consists of white coralline limestone, frequently having a very open structure. The stratum generally has a medium hard to hard consistency. Core photographs indicate that the discontinuities did not follow a pattern based on bedding or tectonic stresses. Breaks appear to be related to weak zones in the rock mass and the presence of fossils including shells. The thickness varied between about 14 and 28 ft in the borings, with an average thickness of 22 ft. The unit weight measurements of 32 core samples from Key Largo varied from 115 to 156 pcf, with an average of 136 pcf. The RQD values measured from 333 rock cores were very inconsistent, varying from 0 to 100%, with an average of 65%.

The Fort Thompson formation underlies the Key Largo formation. It consists of white limestone with varying amounts of vugs and shells and some sand. It is medium hard to hard in upper portions and is medium hard to soft in the lower portions. The thickness measured in the borings varied from about 60 to 68 ft, with an average of 66 ft. The unit weight measurements of 56 core samples varied from 110 to 153 pcf, with an average of about 136 pcf. As in the Key Largo formation, the RQD values measured from 1,098 rock cores were very inconsistent, varying from 0 to 100%, with an average of 57%. Based on ASTM D 6032-02, the quality of the Key Largo and Fort Thompson formations classifies as “very poor” to “excellent”.

V_S data points were obtained from the ten boreholes in which downhole P-S suspension logging was performed. For each rock core depth interval with an assigned RQD value, the V_S data points that fell inside the boundaries of that depth interval were averaged. The corresponding correlation between RQD and $V_{S\text{-avg}}$ is shown in Figure 5 for the Key Largo and Fort Thompson limestone formations, based on the data from the ten deep boreholes.

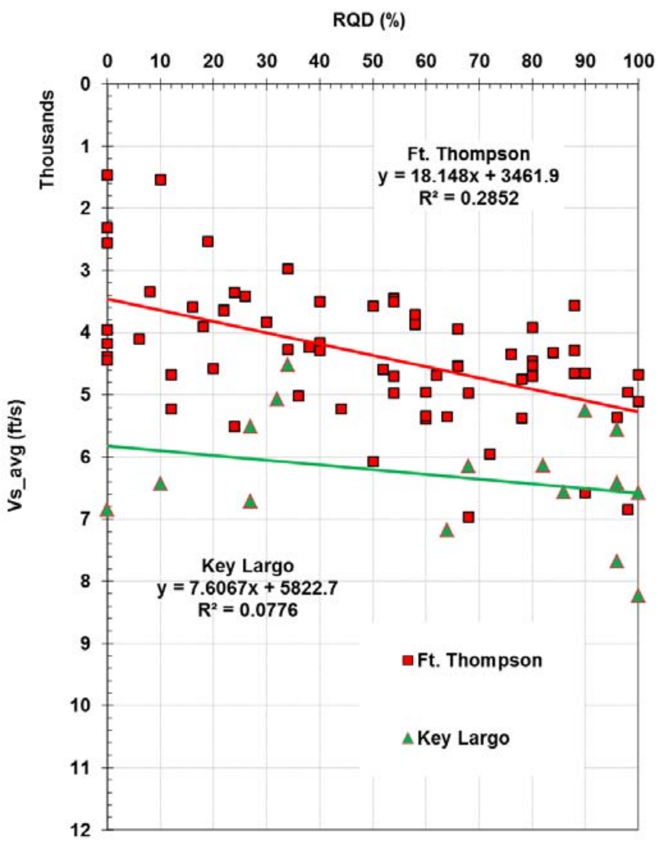

Figure 5. V_S and RQD correlation for sedimentary rock at Florida site

SUMMARY AND CONCLUSIONS

This paper examines the correlation between V_S and RQD for three different rock types located in South Carolina, Virginia and Florida. Reasonable correlations were achieved at the two hard rock sites (South Carolina and Virginia), although the relationships were, as expected, relatively different. The large variability of both RQD and V_S values at the Florida site resulted in a generally weak correlation between the two parameters. The relationships at the two hard rock (igneous and metamorphic) sites were different but predictably closer to each other than to the weaker rock (sedimentary) site.

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GEOVision.
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