<u>Some Geotechnical Engineering Challenges</u>

<u>(Position Paper invited by Engineers Australia, May 2014)</u>

There are three major challenges which I wish to address and they originate in the testing of rocks for underground mining and tunnelling. Over many years I have deplored an overly simplistic approach to complex problems. Some engineers consider a single approach or a limited range of tests when beginning a new project. They do not always take account of all the parameters needed to make the work and its final outcome both productive and safe.

1. "Stability" Is Not The Only Important Criterion.

Most geotechnical engineering investigation, sampling, and testing has traditionally been devoted to providing data for the design of safe structures :

- the natural soil and rock mass underlying or surrounding a man-made construction such as a foundation, slope, cavern, tunnel or borehole, &
- the man-made structure, such as a footing, slope reinforcement, tunnel lining, or borehole lining, interacting with the natural soil and rock mass.

The conventional analysis procedures compare the stresses, strains or bending moments expected to be acting or induced in the natural or man-made materials with the "strengths" of these materials i.e. the maximum values to which they may be subjected before suffering damage, or ceasing to be reliable structural elements.
This concentration on "STABILITY" should be tempered by consideration of "CONSTRUCTABILITY", in the case of the man-made structures, such as bridges, high-rise buildings, footings, and tunnels. Structures that were designed to be safe after construction have been known to fail because of the logistics of construction activities and the temporary loadings that these activities produced in the partially-completed structures.
Similarly, in the natural soil and rock mass underlying or surrounding a man-made construction, "CONSTRUCTABILITY" should be investigated as well as, or even before, "STABILITY".
"CONSTRUCTABILITY" can mean both "EXCAVATABILITY" and "ABRASIVENESS".
The question of EXCAVATABILITY means "How much force and/or work will have to be applied to the soil or rock to break it with tools?" Also, in the case of soils, how coherent is the material? : How may it best be loaded and transported?
The question of ABRASIVITY means "How much damage will be done to the excavating tools while breaking the ground, and how much damage will be done to a transportation system by the fragmented material?"

These important considerations tend to be ignored until after the "STABILITY" design has been finalized, and then the strength parameters which were appropriate for the Stability analysis may be applied, often inappropriately, to the assessment of Excavatability and Abrasivity.
The Unconfined Compressive Strength (UCS) of a soil or rock is often the only strength parameter requested by the designers and/or measured by the geotechnical engineers. The mean value of a small group of test specimens (sometimes only a single test!) may be divided by a Safety Factor of 2 or 3 to derive an "allowable strength" which should not be exceeded in the designed structure if it is to be regarded as "Stable". Alarmingly, this "allowable strength" may also be provided to excavation contractors and machinery suppliers, as a basis for implicitly (and inappropriately) assessing both the Excavatability and even the Abrasivity. There are special and specific test procedures for assessing Excavatability and Abrasivity, and the UCS does not figure highly in them.

A major cause of delays and cost overruns in construction projects may be the provision of inadequate and inappropriate geotechnical data, which did not enable properly informed planning.

2. Natural Variability Is Not Taken Seriously Enough.

It seems bizarre that the effects of natural variability seem to be taken more seriously in the case of manufactured artificial materials (in which variability is small, and specifiable) than in the case of natural soils and rocks (in which variability may be large, and unspecifiable).

The Coefficient of Variation (= Standard Deviation/Mean) or CofV is a measure of the shape of the Gaussian Standard Distribution curve.
Reported values of CofV for structural steel vary from 0.01 to 0.15, with an average of about 0.05
Reported values of CofV for structural concrete vary from 0.03 to 0.2, with an average of about 0.1

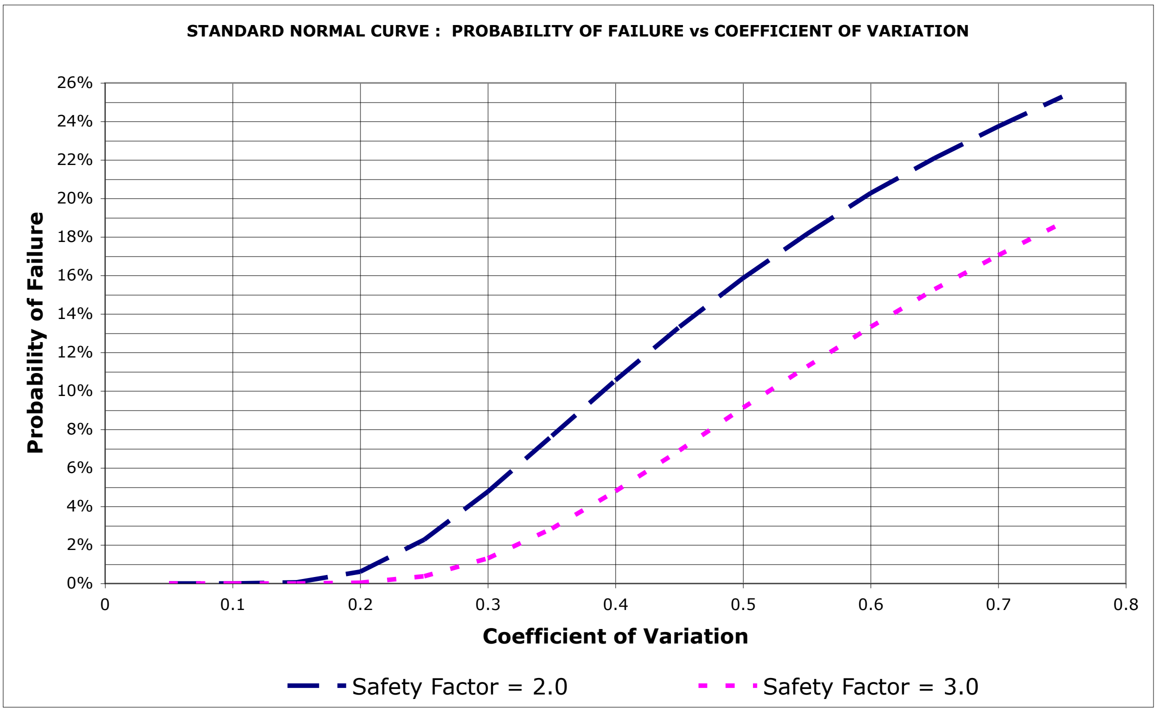

Figure 1.

This graph is derived from the Gaussian Standard Normal Distribution curve It shows that the Probability of Failure when using Factors of Safety of 2 or 3 is negligible for materials such as structural steel and concrete, having Coefficients of Variation usually less than 0.2, but is not negligible in natural soils and rocks, whose measured Coefficients of Variation range from 0.3 to 0.6 and higher.
For example : Measured Mean UCS = 44 MPa, Standard Deviation = 25 MPa, therefore Coefficient of Variation = 0.57
Assuming a Factor of Safety Factor of 2.0, the allowable design stress would be 22 MPa.
The graph shows that there would be a Probability of Failure of 19%, if the design stress was exceeded in service.

Design engineers will usually require that a statistically significant amount of testing be performed, to certify that the variability in strengths of structural concrete and steel is within the limits specified by the purchasers, and guaranteed by the manufacturers, and thereby to certify the reliability of the execution of their designs. By contrast, when using far more variable earthen materials, where the “maker” cannot be contractually obliged to guarantee their quality and uniformity, there is often a reluctance to authorize adequate quantities of testing and this may almost guarantee that failures may occur when design loads are applied.
A concerted effort should be made to educate non-geotechnical engineers in the realities of the magnitudes of natural variability in soils and rocks, and the dire consequences of ignoring them.

3. Apparently Uniform And Well-Known Rock Formations Should Not Be Assumed To Be Characterizable By A Single Constant Strength Parameter.

The Triassic Hawkesbury Sandstone, commonly known as the Sydney Sandstone, is a material in which there is more than 220 years of experience of constructing foundations, slopes and tunnels in Australia's largest city. Its properties are often assumed to be well-known, relatively uniform, and confidently predictable.
More than 400 UCS tests conducted by the author are analysed in the following plots.

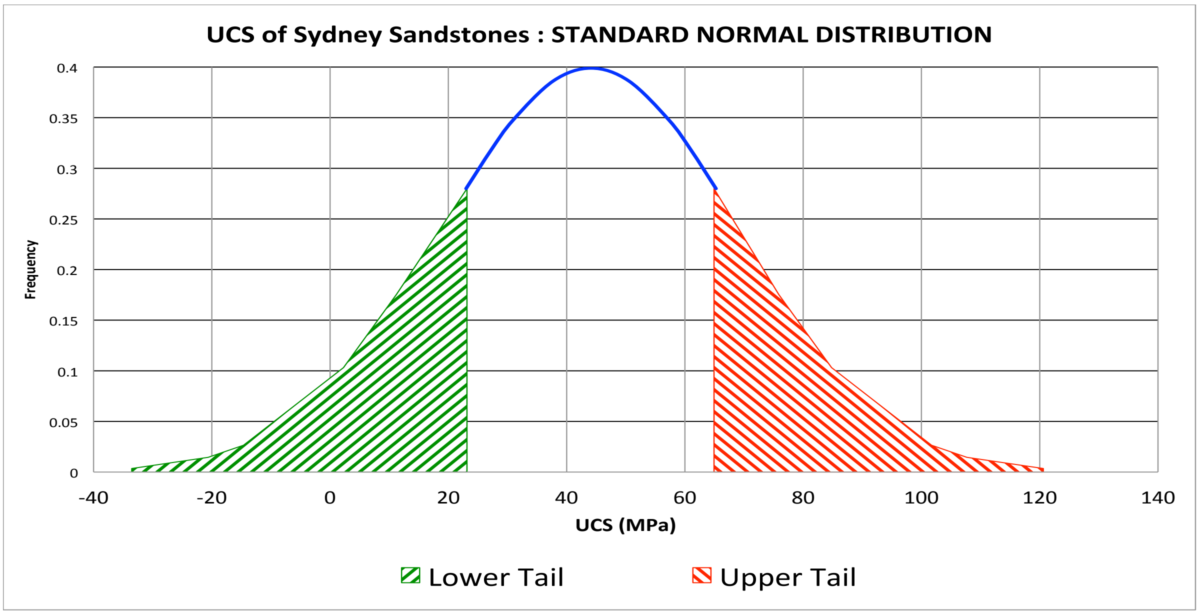

Figure 2. Sydney Sandstones (n=402) Mean = 44.1 MPa Coefficient of Variation = 0.57

For STABILITY calculations : From Figure 1, the measured Coefficient of Variation would lead to a 19% Probability of Failure if the mean UCS was divided by a Safety Factor of 2.0, and the rock was subjected to a stress of 22 MPa; the Probability of Failure would be expected to be 12% if the mean UCS was divided by a Safety Factor of 3.0, and the rock was subjected to a stress of 14.7 MPa.
From Figure 2, there is a 10% Probability that the UCS is < 12.0 MPa, and a 20% Probability that the UCS is < 23.0 MPa.
These figures should be used in foundation design calculations, depending on the magnitude of the risk of failure which is acceptable by the project owner.

For EXCAVATABILITY calculations : From Figure 2, there is a 10% Probability that the UCS is > 76 MPa, and a 20% Probability that the UCS is > 65 MPa.
These figures should be used in construction calculations, depending on the magnitude of the risk of encountering "unexcavatable" material which is acceptable to the construction contractor.

Fitting a Standard Normal curve to the properties of this natural rock produces the unrealistic conclusion that 8% of the samples have negative strengths.
Figure 3 reinforces the point that a Log-Normal Distribution is usually a more realistic depiction of the properties of real earthen materials such as soils and rocks.

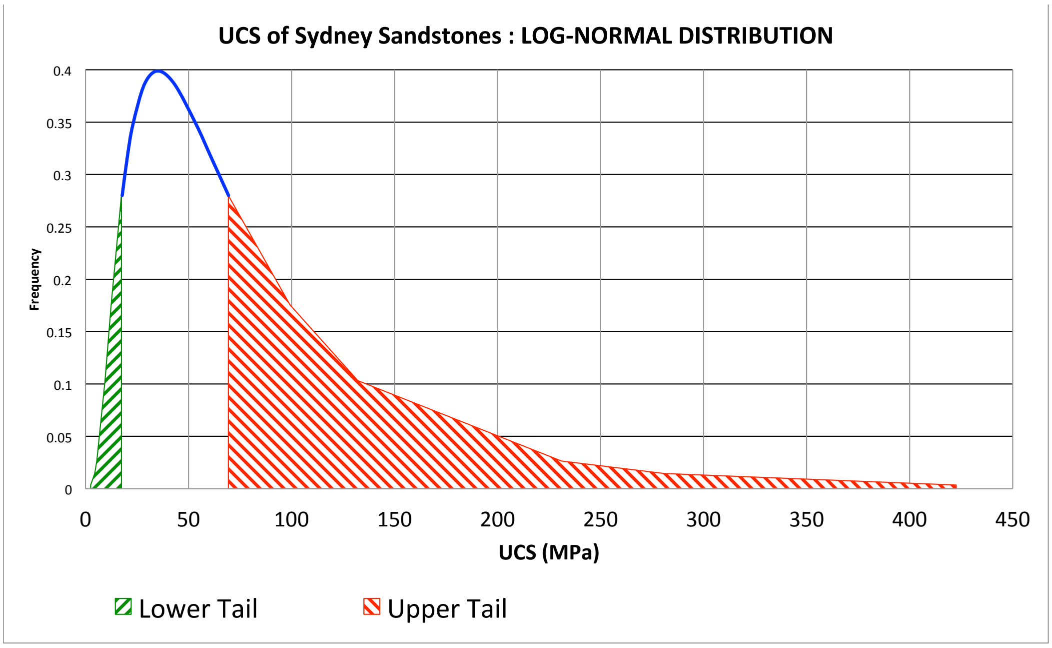

Figure 3. Sydney Sandstones (n=402) Median = 40.6 MPa Coefficient of Variation = 0.06

For STABILITY calculations : From Figure 3, there is a 10% Probability that the UCS is < 12.5 MPa, and a 20% Probability that the UCS is < 17.8 MPa.
These figures should be used in foundation design calculations, depending on the magnitude of the risk of failure which is acceptable by the project owner.

For EXCAVATABILITY calculations : From Figure 3, there is a 10% Probability that the UCS is > 99 MPa, and a 20% Probability that the UCS is > 69 MPa.
These figures should be used in construction calculations, depending on the magnitude of the risk of encountering "unexcavatable" material which is acceptable to the construction contractor.