QUO VADIS TUNNEL ENGINEERING?

PREDICTING THE UNPREDICTABLE

CLOSING LECTURE by Professor Z T Richard Bieniawski v. Preinl

SLIDE-1

It is my distinct pleasure to visit Brazil for the second time and I thank President Rocha and Chairman Celestino for their kind invitation to deliver this Closing Lecture – an honor, which I highly appreciate.

SLIDE-2

My first visit to Brazil took place a long time ago, in 1974 during the 2nd International Congress on Engineering Geology in Sao Paulo but I remember it vividly because my friend, the late Victor de Mello, a brilliant professor and engineer showed me around the site of your world-famous ITAIPU dam and powerhouse and I learned much from that visit. What also helped to keep it in my memory was that next I attended a football match in Rio de Janeiro at the equally famous Maracaná Stadium. As a former football player, I was simply overwhelmed by its size!

Today I am privileged to view Brazil from another angle: that of the Theme to which this Congress is dedicated: "Tunnels for a Better Life", and my function is to assess whether the mission of all of us here, organizers, authors, participants and exhibitors, was achieved in terms of this Theme,
and also to identify what significant developments might we expect in the future.

In this task, I am assisted by the thoughtful Alan Muir Wood Lecture and the Keynote Addresses delivered during the Opening Session.

I had the honor to know personally Sir Alan Muir Wood [SLIDE-3] and we have met on many occasions. We became friends, although he was my senior by some 15 years, and during a number of social hours Sir Alan shared with me his views on what one should expect from attending a World Tunnel Congress! Being of a Scottish heritage with a great sense of humor – he said to me: "With so many congresses and colloquia and symposia taking place every year, I demand of the people that I send to attend: 'bring me back just one and only one good idea which I can use and I will pay all of your travelling expenses plus throw in a bottle of wine'!"

I liked it so much that – today – I have selected three areas of tunnel engineering for you to choose, and will scrutinize what ideas have emerged from each, under my bold title: "Quo Vadis Tunnel Engineering? Predicting the Unpredictable".

SLIDE-4 By the way, the words "Quo Vadis" - as you know - is a famous Latin expression meaning "Where Are You Going?" used to indicate a future destiny.
For us here, to answer our QUO VADIS, I quote this prediction:

**SLIDE-5**

*"The Illiterate of the 21st century will NOT be those who cannot read and write, but those who cannot learn, unlearn and relearn."*  
Alvin Toffler, Futurist

This message will be an umbrella for my Closing Lecture.

**SLIDE-6**

The three topics I selected for your consideration are:

1. Tunnel Design Methodologies,
2. Education for new cadres of tunnel engineers and planners, and
3. Site investigation expenditures needed for effective tunnel design and construction.

Immediately you might ask: "Why predicting the unpredictable? Is this reasonable and possible to do at all – within our life span?

The answer is: Certainly! And it has been done before on an even grander scale!

Please consider this **SLIDE-7** showing the title of a book published not so long ago: "The next 500 Years (!) – Life in the Coming Millennium" by Adrian Barry.

Also shown is an article much closer to our profession: *The next 50 years of the ISRM and anticipated future progress in Rock Mechanics* by John Hudson, president (2007-2011) of the International Society for Rock Mechanics. He
pointed out that Hippocrates, the Greek physician (460-377 BC), used a method for predicting the future which is summarized as:

"Consider the past, diagnose the present, foretell the future".

Emerging Methodologies and Principles of Tunnel Design

"It is not the things we don't know that cause us problems, but the things we think we know for sure."
General Dwight Eisenhower

Yes, this quotation is to remind us that we are all quite sure how we design tunnels, but we should always keep an open mind for new ideas.

In this respect, our ITA Founder Alan Muir Wood insisted on the importance of applying scientific principles to engineering design. This was emphasized in his book (SLIDE-9) "Tunnel Management by Design".

Tunnel design has been treated extensively in other textbooks as well: "Rock Mechanics Design in Mining and Tunneling" (1984) and "Design Methodology in Rock Engineering" (1992). Recently, in 2011, Xia-Ting Feng and John A Hudson published their book "Rock Engineering Design".

SLIDE-11 This latest book points out that "The subject of design methodology is now experiencing and will continue to experience major developments in the future because of new capabilities provided by the use of computer programs that can model the rock behavior in new and more insightful ways."

At the same time, at this Congress and at the last 2013 Rapid Excavation and
Tunneling Conference, a considerable number of papers describing important tunneling projects did not describe specifically any tunnel design methodology used, or only provided a superficial mention. One of the reasons for it is that there is no requirement by the Owners/Planners nor by government agencies to disclose a standard design procedure because it does not exist, except - as in SLIDE-12 - the European Union Eurocode 7 for Geotechnical Design, which allows national variations (such as rock mass strength and predominant stress field) by National Annex Documents (NADs). The United Kingdom has produced one. I believe that Finland and Sweden also prepared their national documents.

In the meantime a workable compromise has emerged with the approach reported from Spain by Dr Celada and his team introducing the DEA (Diseño Estructural Activo) concept, translated as "Interactive Tunnel Design Methodology". This is depicted in this and the next SLIDE-13, dealing with the three phases of DEA: Site Characterization, Design Procedure, and Tunnel Construction. The details and advantages were discussed by Dr Celada at this Congress, and are available on my website.
I would like to suggest that, in the spirit of Alan Muir Wood's recommendation of taking home "one thought provoking idea", we should make a resolution such as this: "Be specific when describing the chosen tunnel design methodology and use it as a check-list (similar to what a pilot does prior to take off) to ensure that all aspects of the undertaking are incorporated."

Training Tunnel Engineers and Educating Planners/Owners

"Each modern profession worthy of its name requires three elements: Theory, Education and Practice. The reason: they are needed to guarantee its capacity for renewal and development."

Philosopher Herbert Simon (1969)
With reference to the above quotation, the profession of tunnel engineering, supported by the science of rock mechanics, certainly may pride itself on having theory as one of its elements and the presence of magnificent tunnels and other underground works provides plenty of proof for well-established practice in our field, going back to the times of King Hezekiah (700 BC) whose tunnel is mentioned in the Bible (2 Kings 20:20).

But what about the element of education? Here we have two challenges:

(i) education of new tunnel engineers and engineering geologists through dedicated degree programs and continuing education which are currently lacking at most technical universities, not only in South America but also in Europe and in North America. I can speak from first-hand experience having taught in the USA and in Spain, Great Britain and in Poland.

SLIDE-16

To be more specific, a recent study (2010) on "Education in Underground Science and Engineering" by the Rock Mechanics Foundation, stated its findings as follows:

"The current status is that graduate education in rock engineering does not have a broad base of support among institutions of higher learning. For example, among the approximately 200 civil engineering departments studied, less than 10% have substantial graduate programs in rock mechanics; those with
geotechnical programs are mainly focused on soil mechanics. Most universities with mining departments do have rock mechanics, those are few in number and departments tend to be small."

At this Congress, an excellent initiative took place during the pre-Congress ITA Training Session about tunnels for energy. Its classes, conducted by professionals and experts, certainly enhanced the education and training of graduate students and young professionals.

This was a worthy initiative but only an exception to the current stagnation status in rock tunneling training and education at universities.

SLIDE-17

(ii) The second challenge is to educate non-technical persons involved in planning tunneling projects or being owners or government officials administering underground projects. These people long to be better informed about the finer aspects of tunneling, applications and use, as well as cost control – but where should they seek such education? I believe that the tunneling community should provide such opportunities.

So, once again, in the spirit of Alan Muir Wood's vision, please make a note of this "thought-provoking idea #2".
Explore further possibilities for improving training of young tunnel engineers – men and, yes, women – as well; if you are a professor or a teacher, take the initiative at your institution of higher learning, if you are in the tunneling business, help secure funds for a new industrial course; if you are neither: write articles to the press and the media suggesting action for the benefit of the society.

Finally, for all of us at this Congress: let us support the concept of "continuing education" for tunnel engineers and engineering geologists, and "short courses" for non-technical tunnel planners, administrators and government officials to become better acquainted with our field and its practitioners.

Looking at this SLIDE-19 of students in college, we must ask:

"What can we do to attract these students to our fascinating profession?"

When is "Enough" sufficiently Enough for Tunnel Site Investigations

"Not all experience is necessarily good. We must learn only the best practices - those used most widely in the most successfully competitive firms" - John Dixon (1991)

We often plan the scope of site investigations based on our experience with similar projects. The quotation above warns us to be careful, as not all experience is necessary good.
When I look back on my 50 years of involvement in rock engineering (since 1963) I notice a peculiar trend, which concerns me – site investigations for tunnels. In the first two decades of my tunneling activities, I saw tremendous developments of new site investigation techniques and the increasing scope of site investigation programs based on the understanding that spending sufficient time and money in the early phases of a tunneling project will ultimately save on design and construction, will provide increased safety and will avoid costly disputes or corrections of wrong guesses. Oddly enough, in the past two decades I noticed precisely the opposite trends: as the owners/planners tried to trim their budgets and tunnel designers competed for projects, the first thing cut to reduce costs and completion times, was the scope of site investigations. Increasing emphasis was placed on computer modeling both to impress the owners with colorful graphics and to demonstrate having "cutting edge" technologies.

In fact, a stage was reached where the sophistication of analytical modeling far exceeded the level of reliability of the input data on rock mass properties from limited site investigations. All of this leads to a question, which has been asked before but which is more pressing today because of the emergence of mega-tunneling projects: "When is enough Enough" for tunnel site investigations?

One answer came from the US National Committee on Tunneling Technology (USNC/TT) who published a major study in 1984 entitled
"Geotechnical Site Investigations for Underground Projects": Review of Practice and Recommendations" and concluded with these guidelines:  

"Expenditures for geotechnical site exploration should average 3% of the estimated project cost."

Experience shows that today typical levels are less than 1%, which is totally incompatible with the over 10% average of project cost doled out in payment of legal disputes, usually for unexpected subsurface conditions.

However, the USNC/TT recommendation requires considerable planning and justification; the report states: "The geotechnical site investigations cannot predict every problem that may be encountered, and attempts to do so generally result in programs that are disproportionately expensive for the value received. For every underground project, cost-benefit is a key element."

SLIDE-23

Determination of rock mass deformability, that is, the in situ modulus, is an example of current deficiencies.
Can you remember a recent large-scale test such as the large flat jack test (SLIDE-24) or these tests (SLIDE-25) conducted in your country?

In fact, they are not commonly in use. Instead, we are using correlations based on rock mass quality which, however, are only as good as can be confirmed by actual in situ measurements performed on the given project.

So, once again, in the spirit of Alan Muir Wood's vision, please make a note of this "thought-provoking Idea #3 (SLIDE-26):

"Let us ensure that sophistication of analytical modeling matches the reliability of the input data on rock mass properties – best determined from dependable field tests!"

SLIDE-27

QUO VADIS TUNNEL ENGINEERING?

To answer this question, first the good news in SLIDE-28: "The World in 2014" is - the cover of the leading international news magazine THE ECONOMIST, presenting the most significant and expected developments for this year.
On page 123, is the article: "Great Bores of Tomorrow: Record length of tunnels will be dug in 2014." It predicts a length of over 1000km of tunnel to be constructed this year, and emphasizes – guess what? – yes, the benefits of tunneling and underground space development! It concentrates on the use of boring machines, which we know as TBMs, and singles out their potential in Latin America, as an answer, among others, to "traffic-choked cities."

It encourages governments to be "more adventurous" with tunnel projects and concludes with the prediction: "An exciting future beckons for tunnel boring."

In terms of coverage by the papers presented at this Congress, dealing with the three areas I discussed, the topic of DESGIN received most attention with 38 papers actually emphasizing this term in their titles.

At the same time, NO PAPERS dealt with education and training of tunnel engineers and non-technical personnel. Perhaps, at the next Congress, WTC 2015 in Dubrovnik, a special session might be devoted to this topic? I challenge our organizing friends from Croatia to consider this, please!
Finally, site investigations for tunneling were addressed in many papers, presenting varied scopes of tests and studies, but I could not find guidance to answering the question: "When is enough, enough?" to compare with an earlier statement by Feng and Hudson (2011):

"Currently there is no international procedure for checking suitability of rock engineering design, but it is likely to be implemented in the future. Site information auditing as a component of the overall technical auditing will be a key element for validation of rock engineering design methodology."

**Predictions:**

*Something Expected and Something New*

SLIDE-29

Let us now consider what might lie ahead in terms of our future challenges, particularly in South America. And let us remember the quotation I presented at the beginning, from the futurist Alvin Toffler:

"The Illiterate of the 21st century will NOT be those who cannot read and write, but those who cannot learn, unlearn and relearn."

SLIDE-30

**Something Expected:** Consistent with the current trend, we can expect and predict that the use of TBMs and further mechanization of tunneling operations will grow considerably in the future. I recommend, as
one priority, the development of techniques able to assess rock mass conditions ahead of TBMs as construction proceeds in real-time.

As underground excavations will become larger, longer, deeper and more complex, they will also become more difficult to execute and will be more expensive. [I remember the times when a TBM cost a few million dollars; last year the Seattle machine cost $80 million] Hence tunnel design will be more challenging and will dictate more extensive site investigations, including large-scale field tests, and exploratory pilot tunnels. In essence, reliable input data from field tests to determine rock mass properties will be fully justified to match the sophistication of computer modeling techniques.

SLIDE-31

Something New: In South America, where the lore of the Andes was enshrined in poems and songs, such as the Peruvian "El Cóndor Pasa" by composer Daniel Alomía Robler and sang by Simon & Garfunkel, tunnels can be expected to be built for accessing the great reserves of copper, silver, gold and the strategic minerals needed for new technologies. These tunnels will be placed at greater depths than currently, in conditions where rock-bursts and high water pressures will hinder them. I read that rock-bursts were observed during the construction of the Olmos Trans-Andean Tunnel in Perú.

In addition, certain geotechnical practices will have to be revised; not only by more extensive site investigations as mentioned earlier to provide reliable input data for design purposes, but also by developing improved
modeling to include the effects of *plastification* under great stresses, and to incorporate post-failure mechanisms, as well as - in special cases - deal with *coupled problems* of a mechanical-hydro-thermal-chemical nature.

For tunnel boring machines (TBMs), the use of which will be more extensive, the challenges will be to bore tunnels under high rock pressures and high water pressures, both in hard rock and in soft ground conditions; these challenges are simply extraordinary. Thus we need to acquire improved understanding of, and the ability to predict the effects, of ground stresses and their changes, and of the phenomenon of rock-bursts and the measures for their amelioration.

In all this, the potential of geophysical techniques should not be overlooked. They will become more extensive due to their rapid development as technologies improve. Finally, monitoring and convergence measurements during construction will become indispensable under more difficult conditions.

**CONCLUSIONS**  [SLIDE-32]

In concluding this presentation, I wish to congratulate the Congress Organizers for making this occasion such a significant event for the tunneling community and for increasing the awareness of society at large to the benefits and achievements of our profession.

We have shown that in the future we need to pay better attention to tunnel design methodologies, to better education of new tunnel engineers
as well as non-technical planners and administrators, and to better cost-benefit driven site investigations.

**SLIDE-33**

Today, the time has come for me "to ride into the sunset" which means that after a long career, I need to "hang up my hard hat" and this is my last venue to leave you with a farewell message. As I happily conclude my professional activities in the theory and practice of tunnel design and construction, I say "happily" because I have discovered a personal secret to achieving full satisfaction in my chosen profession and I want to share it with you. The secret is simply to involve your spouses or life partners in your work; my wife of 50 years of marriage has always been at my side editing my books, papers and often finding ways to improve them, as well as listening to my presentations at many conferences.

**SLIDE-34**

In fact, she is here with me at this time not just as an accompanying person but also as a partner in technical matters. Believe me, a happy spouse is a fine investment for a successful and enjoyable tunneling career! This photograph was taken last year on our 50th Wedding Anniversary, so she tolerated my tunneling “addiction” for all these years!

**SLIDE-25**

And on this note, as we are about to adjourn for the Gala Banquet, may I suggest that you contemplate, in the spirit of Alan Muir Wood, just
what is *that ONE best idea that you have acquired at this Congress*, and please share it with your companions at the Gala. It will inspire others to share and discuss their best ideas with you! And who knows? When you get back to your office, and share your best idea with your boss, you might even win a bottle of fine wine!

The future of tunneling seems secure to me and I wish to leave you in high spirits with this quotation:

SLIDE-36

"Enthusiasm is the greatest asset in the world; it beats money, and power and influence."  (Henri Chester)

SLIDE-37

*Muitíssimo obrigado pela boa atenção que vocês deram ao nosso trabalho!*