COMMON GROUND

Norbert R. Morgenstern[1]

ABSTRACT

This Keynote Address highlights the unifying elements in geotechnical theory and practice. Unifying concepts, history, achievements and challenges are reviewed. It is emphasized that major value added contributions arise from an integrated or holistic approach to geotechnical engineering. The current organization of the geotechnical community is not adequate to foster this approach. The formation of an International Geotechnical Union is advocated in order to better meet the challenges of the new millennium.

1.0 INTRODUCTION

This singular event, Geo Eng 2000, supported by all the main members of the geotechnical family, provides an opportunity to ask a number of questions and reflect on the nature of our profession early in the new millenium:

- Who are we?
- What do we do?
- How did we come into being?
- What have been our accomplishments?
- How do we add value now in engineering practice?
- What special problems confront us?
- Do we need change or is it business as usual?

Each of these questions will be addressed in the following. The perspective is necessarily personal. It will be argued that, notwithstanding the achievements of the past and the exciting new developments provoking change in geotechnical engineering in recent years, the way in which geotechnical engineering adds value is not adequately understood, recognized and rewarded. Examples will be given to illustrate that the way forward to resolve this issue requires emphasis on unification, as opposed to specialization, in geotechnical engineering. This emphasis, "Common Ground", must be highlighted not only in geotechnical practice but also in educational and research programs. A new organizational structure, an International Geotechnical Union, is necessary to promote this vision.

2.0 WHO ARE WE?

Recent efforts in the United Kingdom to create a unified body to provide a technical, professional focus for geotechnical matters have contributed a definition of geotechnical engineering that is comprehensive (Anon, 1999):

> "Geotechnical engineering is the application of the sciences of soil mechanics and rock mechanics, engineering geology and other related disciplines to civil engineering construction, the extractive industries and the preservation and enhancement of the environment.
>
> Geotechnical engineering plays a key role in all civil engineering projects, since all construction is built on or in the ground. In addition it forms an important part of extractive industries, such as open cast and underground mining and

[1] Norbert R. Morgenstern, University of Alberta, Edmonton, canada, T6G2G7

hydrocarbon extraction and is essential in evaluating natural hazards such as earthquakes and landslides.
The use of natural soil or rock makes geotechnical engineering different from many other branches of engineering: whereas most engineers specify the materials they use, the geotechnical engineer must use the material existing in the ground and in general cannot control its properties."

3.0 WHAT DO WE DO?

Anon (1999) also discussed the practice of geotechnical engineering and noted that it often encompasses a wide variety of skills involving many types of professionals concerned with the ground; e.g. civil and structural engineers, tunnelling engineers, mining engineers, geotechnical engineers, engineering geologists, geologists, hydrogeologists, geophysicists, geochemists, etc.

Figure 1, modified from Anon (1999), suggests that the main deliverables of geotechnical engineering are: i) structural support systems, ii) fluid control systems, iii) underground geo-structures, iv) surface geo-structures and v) ground improvement. As indicated, geotechnical engineering draws not only on relevant scientific and engineering fundamentals, but also on public policy restraints, construction practice, and risk management.

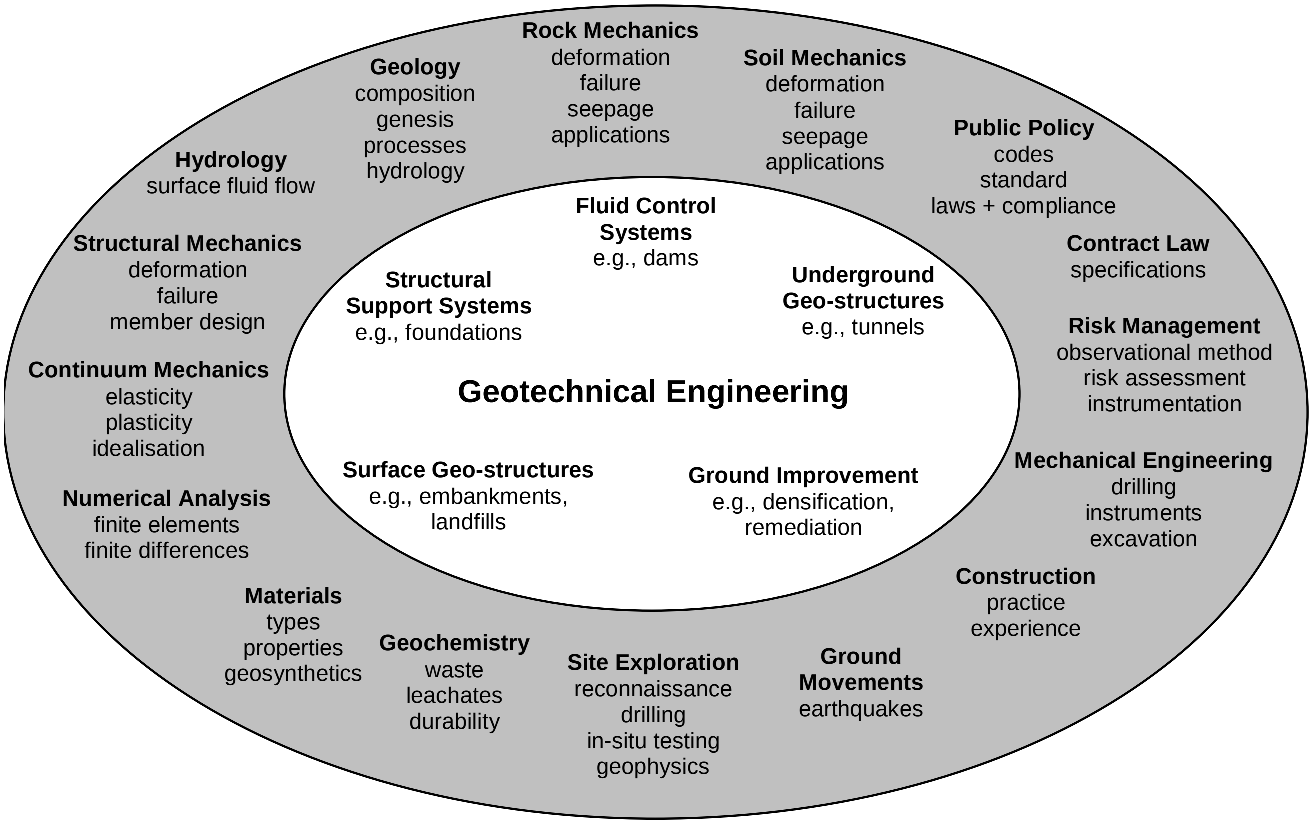

Figure 1. The practice of geotechnical engineering encompasses a wide variety of skills; modified from (Anon, 1999).

Morgenstern (2000) recently emphasized that uncertainty is chronic in geotechnical practice and therefore risk must be managed. An essential component of assuring geotechnical performance, over the wide range of deliverables, requires that the geotechnical engineer maintain an on-going awareness of factors that contribute to unsuccessful performance and introduce this awareness into comprehensive risk management tools.

The geotechnical method is not serial, but instead involves feedback between data acquisition, material and model idealization, technical evaluation, judgement and risk management. While performance codes and methods standards are useful, more penetrative standardization of geotechnical design is counter-productive. The interactive aspects of the geotechnical method are illustrated in Figure 2, also adapted from Anon (1999). The dominance of particular linkages and feedback loops will vary from project to project.

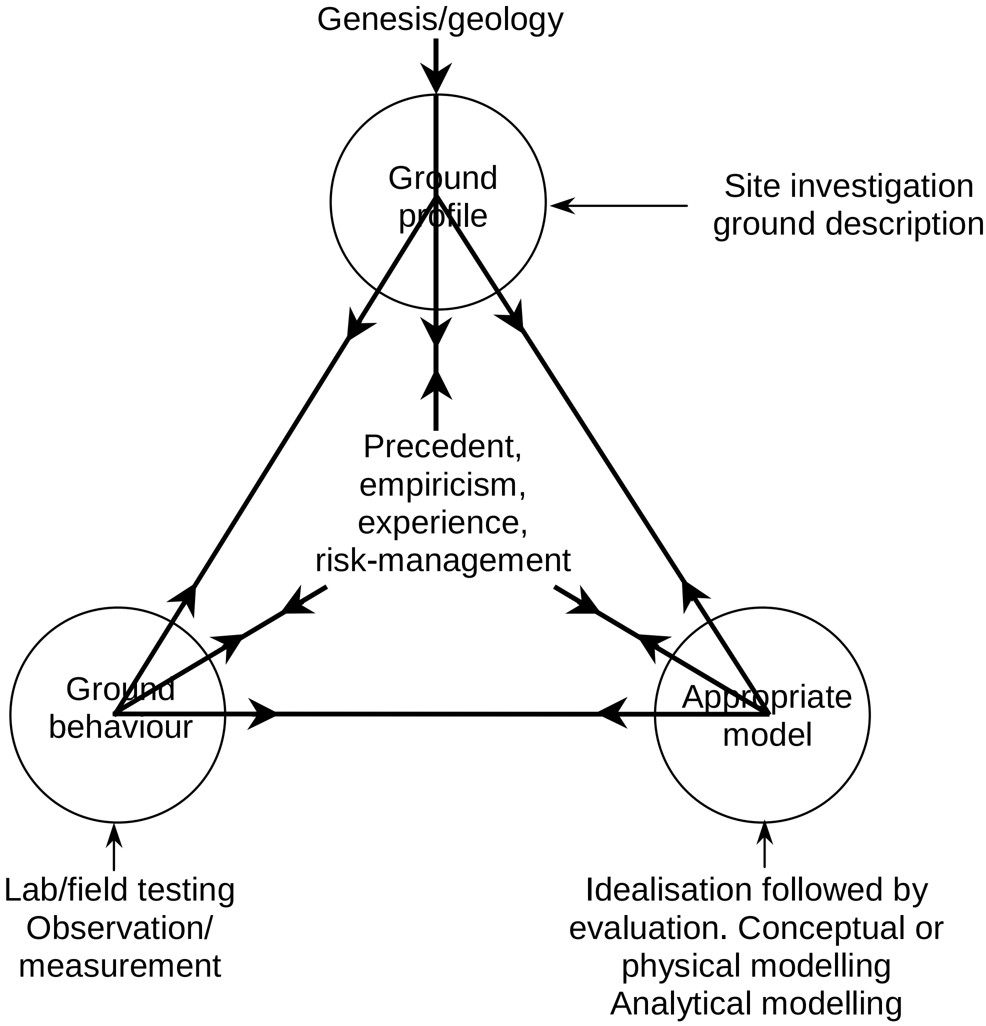

Figure 2. The geotechnical triangle. Each aspect is distinct but interlinked.

The geotechnical method also recognizes several unifying concepts. They can be illustrated by reference to the origin-consistency matrix of geo-materials shown in Figure 3 that demonstrates the wide range of materials considered by geotechnical engineers. The distinction between soil and rock is based on whether or not the material disintegrates when submerged in water and the boundary between weak and strong rock is taken at the compressive strength of common concrete. Neither boundary is razor-sharp. Clay-shales are transitional materials between soils and rock that are difficult to classify with precision. The distinction of strong rock is intended to imply that the strength of the intact rock is generally too high to be of geotechnical significance. However, while often true for many geotechnical problems, important exceptions exist. Studies by Martin and his co-workers (Martin, 1997) on the behaviour of deep openings in highly stressed granite have shown that progressive failure affects the boundary and the shape of the excavated opening. This has an important bearing on the integrity of nuclear waste repositories planned for such host media.

Referring to the range of materials illustrated by Figure 3, a geotechnical engineer may be called to evaluate liquefaction in a recent alluvial sand or design a tunnel in a Cretaceous marine clay-shale or advise on a deep excavation through a weathered granite profile. The unifying concepts that facilitate this breadth of endeavour are:

i) All of the materials are porous (to varying degrees) and the concept of effective stress provides the fundamental basis for quantitative characterization.

ii) All of the material (to varying degrees) are normal stress dependent; strength increases with normal stress, stiffness increases with normal stress and permeability generally decreases with normal stress.

iii) All of the materials (to varying degrees) are structure-dependent; for some, like homogeneous uniform clays, the structure is at a scale that can be characterized by the process of sampling and testing; for others, like a jointed, hard rock mass, the discontinuity fabric dominates behaviour and scale effects limit the role of sampling and testing.

4.0 WHERE HAVE WE COME FROM?

4.1 Soil Mechanics

The emergence of soil mechanics has been well chronicled (Terzaghi, 1957; Goodman, 1999). While important contributions to earth pressure theory had been made in the 18th century and to slope stability analysis in the 19th century, the subject remained incoherent until Terzaghi recognized "that engineering geology cannot possibly become a reliable tool in the hands of earthwork engineers unless and until we acquire the capacity to assign to each material of the earth numerical values which make it impossible to mistake it for another one with significantly different engineering properties".

Armed with this conviction and working in isolation at Robert College in Turkey, Terzaghi realized in 1918 the need for systematic experimentation and within a few years he had made brilliant progress, culminating in his recognition of the concept of effective stress. The publication of Erdbaumechanik auf Bodenphysikalischer Grundlage (Terzaghi, 1925) marks the emergence of soil mechanics as a discipline in its own right. This volume integrated soil description and classification, fundamental frictional properties, deformation and strength, and the theory of consolidation together with various applications in foundation engineering.

In 1929 Terzaghi returned to his more geological interests and published his classic "Effect of minor geological details on the safety of dams". Notwithstanding the scientific advances that he had initiated, this contribution highlighted the uncertainties that are an essential part of geotechnical practice and , as noted by Terzaghi (1961), led to the articulation of the observational method. He had not only laid the scientific basis for much of soil mechanics but had also provided the risk management procedures for its successful application in practice.

The first International Conference on Soil Mechanics and Foundation Engineering in 1936 marked the start of the period of widespread recognition and acceptance of soil mechanics in engineering practice.

4.2 Rock Mechanics

The first Congress of the International Society of Rock Mechanics was convened in Lisbon in 1967 with about 800 participants and 300 accompanying persons. As summarized by Rocha (1967), President of the Organizing Committee, 42 countries were represented and the interest in rock mechanics was shared by a diverse group of specialists including mineralogists, petrologists, geologists, tectnophysicists, geophysicists, mining engineers, civil engineers, petroleum engineers and others. Although there was much overlap in both technical content and audience with the soil mechanics community, it is unlikely that the identification and support of such wide interest in rock mechanics would have been achievable without the formation of a new, identifiable, international society with such clear interests and mandate.

Origin and Composition / Consistency		Sedimentary					Igneous and Metamorphic
		Clastic		Chemical		Organic	
		Arenaceous	Argillaceous	Carbonates	Evapourites		
SOIL	Cohesionless	Alluvial Sand and Gravel	Rock Flour	Calcareous Sands	Gypsiferous Sands	Topsoil	Talus
	Cohesive	Oil Sand	Clay Clay Shale	Ooozes Marl		Peat	Laterite
	Slaking and Softening						
ROCK	Soft Compressive Strength 500 kPa	Friable Sandstone	Mudstone	Chalk	Gypsum	Lignite	Weathered Granite
	Hard	Sandstone	Shale	Limestone	Potash	Coal	Granite

Figure 3. The Range of Geotechnical Materials by Origin, Composition and Consistency

While 1967 marks the coming of age of rock mechanics there had been a number of symposia and organizational structures in various countries prior to that time. In the United States there had been eight symposia on rock mechanics since 1956. Other countries followed with national meetings in the 1960's. The mining community had convened meetings on Strata Control and Rock Mechanics. Meetings on specialist topics had been held prior to 1967 and aspects of rock mechanics appeared on the technical programs of the International Commission on Large Dams, the International Society of Soil Mechanics and Foundation Engineering and the Internationales Büro für Gebirgsmechanik. However the dominant pioneering effort that crystallized in the formation of International Society of Rock Mechanics was made by Leopold Müller.

Müller (1967), in his closing address to the first Congress, describes how in 1951 sixteen men gathered at his house to try and arrive at a synthesis of geology, geophysics, science of construction materials, mining and construction engineering, to be called "geomechanics". This group in Salzburg became known as the Austrian School and their journal, originally Geologie und Bauwesen, and then Rock Mechanics, was the vehicle for promoting interest in rock mechanics. This culminated in the formation of the International Society of Rock Mechanics.

While Müller deserves enormous credit for bringing the ISRM to fruition, he himself recognized the scientific influence of Stini (Müller, 1979). Stini, who was Professor of Technical Geology in Vienna from the 1920's to the 1940's, was among the first to introduce statistical joint measurements and originated the concept of "Kluftkorper" or joint body. He also made major contributions to slope stability and other aspects of engineering geology.

If there is one major distinction between soil mechanics and rock mechanics, it is the emphasis in rock mechanics on discontinuity behaviour and the properties of jointed media. This paradigm has influenced much of rock mechanics theory and rock engineering practice. It has resulted in powerful numerical methods that we enjoy today for analysing all aspects of the behaviour of discontinuous media and it has focussed our attention in the field on the critical elements controlling the engineering behaviour of both rock and many soil masses.

It is of interest to note that in 1961 Terzaghi's attention was almost entirely concentrated on rock mechanics (Terzaghi and Voight, 1979). He became convinced that the variability of rock masses, combined with the great expense of available testing procedures, precluded the possibility of obtaining sufficient information for a reliable computation of slope stability (and, by inference, other aspects of the behaviour of jointed media). His statements in 1963, at the end of his life, comparing the capacity of soil and rock mechanics to solve geotechnical problems is worthy of review as a benchmark in the evolution of geotechnical engineering. Was his prognosis correct?

4.3 Engineering Geology

The first Congress of the International Association of Engineering Geology was held in Paris in 1970. Professor Q. Zaruba was the first President of IAEG and Professor J. Goguel was President of the Congress. About 400 members from 40 different countries gathered to discuss 119 papers and to plan the future growth of the IAEG. Arnould (1970) has described the history of the establishment of the IAEG which goes back to the 22nd International Geological Congress held at New Delhi in 1964. Following the initiative of a group of experts who felt that engineering geology was being neglected, the International Union for Geological Sciences established a Committee on Engineering Geology in 1964 to advise on its future. IUGS took no action on the subject in 1966 and the experts decided to create IAEG with Dr. A. Shadmon as the first President. Formative meetings were held in 1967 under the patronage of UNESCO and scientific activities emerged in 1968, particularly associated with the 23rd International Geological Congress in Prague, where the first General Assembly of IAEG convened. Therefore, although 1970 marked the recognition of Engineering Geology in terms of international institutions, and the Bulletin of IAEG was started in that year, concerted organizational efforts had preceded this since 1964.

While the international organization of engineering geology can be fixed at 1970, the practice of engineering geology has a proud tradition that precedes this by a considerable length of time. The monumental history by Kiersch (1991) documents this history in detail. Legget (1962) also provides a comprehensive history.

Many examples of dam, tunnel, railroad and canal construction can be cited to show that interest in geology as applied to engineering works grew steadily throughout Europe in the late 1800's. By the early 1900's geological counsel was commonly accepted for the planning of industrial expansion, as the progressively larger engineering structures usually meant a proportionately greater number of complex geological problems for engineering practitioners.

The same can also be said of the United States. Kiersch cites Professor W.O. Crosby (1850-1925) as the "Father of Engineering Geology in America" both as a result of his consulting practice and his academic work at the Massachusetts Institute of Technology. In Europe the influential work of Stini has already been cited and the publication by Redlich et al. (1929) was an important event in the subject. Pioneers can be identified in every country undergoing industrial development at the time (e.g., Lapworth, 1911; Lugeon, 1933; McDonald, 1915; Zaruba and Mencl, 1963).

While the special scientific principles underpinning soil and rock mechanics are readily discerned, those of engineering geology are more elusive. Berkey (Paige, 1950) was undoubtedly the most influential engineering geologist of his time in North America and as a result of his efforts geologists found employment in most large civil engineering organizations engaged in locating, planning and constructing large civil engineering projects. In their discussion of the influence of Berkey and the role of the geologist in such organizations, Burwell and Roberts (1950) isolated the requirements of the engineering geologist as follows:

1) "Obviously, the first requirement of the engineering geologist is that he shall be a competent geologist. ……Against this background of knowledge, he will discover the major geologic factors in advance of construction and recognize the more obscure minor details that so often exert a major influence on location, design and construction problems."
2) "The second requirement is that he shall be able to translate his discoveries and deductions into terms of practical application. This qualification is not obtained as a result of better knowledge of geology, but of better knowledge of engineering."
3) "The third requirement is dual in character. It is the ability to render sound judgements and make important decisions. …..Sound judgment is a priceless faculty of the geologist who is frequently called on to make decisions without all the factual data necessary to guarantee the results. It is not always economically practicable to eliminate the element of uncertainty and not infrequently his advice has to be based on few and scattered evidences in the field."
4) The fourth requirement relates to the temperamental make-up or personal qualities of the engineering geologist. "He should not be an alarmist. Neither faults, nor earthquakes, nor cavernous limestones, nor pervious basalts, nor low water tables should deter him from rationalizing the field evidences and proceeding to logical conclusions based on due consideration of both facts and influences."

This early description of the modus operandi of an engineering geologist finds some resonance in Zaruba's (1970) summary of his 50 years of practice where he advises: "the engineering geologist should be very sober in his conclusions, to keep painstakingly to the objective facts and avoid even the most ingenious inferences".

It is of interest to assess whether or not this classical inductive approach limits the role of the engineering geologist. In a now obscure paper, Morgenstern and Cruden (1977) analyzed the nature of geotechnically complexity at a given site and indicated how complexity arises from three kinds of processes acting either singly or in consort:

i) genetic processes
ii) epigenetic processes
iii) weathering processes

They discussed how process models can contribute to the unravelling of complexity on sites by clarifying the understanding of the distribution of geotechnical properties within a site. This is similar to the more comprehensive arguments in favour of geological model-making put forward by Fookes (1997):

> "The strength of the geological model is in providing an understanding of the geological processes which made the site. This enables predictions to be made or situations anticipated for which explorations need to be sought in the geological materials, geological structure and the ancient and active geological processes of the area. It provides a rational basis for interpretation of the geology

> from understanding and correlation of observed geological features and exposures. Also it can provide an indication of the potential variation in the properties of the soil or rock mass and hence possible errors in calculations or assumptions, especially those assuming homogeneity."

As stressed by Morgenstern (2000), in geotechnical practice, risk must be managed to overcome limitations of site characterization, knowledge of material properties, other unknowns and the vagaries of construction practice. This emphasis on geological model-making applied to geotechnical engineering elevates the role of the engineering geologist as a risk manager. The value of geological model-making is already well-recognized in petroleum engineering.

5.0 WHAT HAVE WE ACCOMPLISHED?

Terzaghi's Erdbaumechanik was published in 1925. Stini's Technische Geologie appeared in 1922 and the journal that he initiated Geologie und Bauwesen, was started in 1929. Redlich, Terzaghi and Kampe's Ingenieurgeologie was published in 1929.

In North America, the benchmark volume produced by the American Institute of Mining and Metallurgy, Geology and Engineering for Dams and Reservoirs, also came out in 1929. Many other classics followed shortly thereafter. Modern geotechnical engineering emerged between 1920 and 1930 and it is convenient to adopt 1925, the date of publication of Erdbaumechanik as the pivotal year. Much has been achieved by the geotechnical community in the subsequent seventy-five years.

Engineering News Record (1999) lists 125 top construction projects over the past 125 years and, starting with 1925, it is possible to select a number of examples that are geotechnically intensive:

- Tunnels (Holland Tunnel, 1927; Cascade Tunnel, 1928; Channel Tunnel, 1994/ Seikan Rail Tunnel, 1988)
- Dams (Hoover Dam, 1935; Guri Dam, 1968; Aswan Dam, 1970; Snowy Mountains Project, 1974; Nurek Dam, 1977, James Bay Project, 1985; Itaipu Project, 1991).
- Highways (Alaskan Highway, 1942)
- Navigation Projects (Mississippi River Locks and Dams, 1940; St. Lawrence Seaway, 1959).
- Bridges (Humber Bridge, 1981; Northumberland Straits Bridge, 1996).
- Pipelines (Trans Alaska Pipeline, 1977)
- Offshore structures (Statford B. Platform, 1981; Hibernia Platform, 1997)
- Subways (Washington, D.C., 1976)
- Airports (Chek Lap Kok, 1998)

To those civil engineering monuments could be added a comparable list of geotechnical contributions to mining and hydrocarbon extraction as well as to environmental improvement through ground remediation.

Less visible, but equally important, are the geotechnical contributions to building infrastructure in virtually every country in the world.

6.0 WHAT ARE THE AGENTS OF CHANGE?

Geotechnical engineering is continually being transformed by the push of new technology and the pull of new problems. Change is particularly evident over the past twenty years.

Everyone will have a different list of the major technical advances affecting geotechnical practice and research over the past twenty years. Mine includes the following (in no particular order):

- Advances in numerical modelling
- Advances in instrumentation and data processing
- Soil reinforcing, including soil nailing
- Advances in ground improvement techniques (grouting, compaction, etc.)
- Applications of geosynthetics
- Advances in in-situ testing
- Application of geophysics

New or greatly intensified applications of geotechnical engineering have developed in the following areas:

- Emergence of environmental geotechnics
- Cold-regions geotechnical engineering (permafrost, ice, frost)
- High-temperature geotechnical engineering (nuclear waste expositories, in-situ hydrocarbon production).
- Application to mining (tailings dams, heap-leach, dumps)
- Applications to petroleum recovery (well-bore stability, reservoir compaction).

The processes driving change in the future, that intimately affect the profession, can be best understood by reference to Knill's (1997) insightful paper. While written in the context of challenges to engineering geology, it can be read as relevant to the whole of geotechnical engineering.

Knill stated that environmental change is taking place primarily as a result of two factors: population growth and climatic changes, issues that are inevitably closely associated. He points out that the most likely projections for population growth peak at 11 billion in the final decades of this century (from the current 5.8 billion), about 90% of the increase will be located in developing countries and at least 60% of this increased population will be living in megacities. Some estimates indicate the need to build the equivalent of 400 huge cities over the next 50 years. This increased population will require housing, food, clean water and effective waste disposal for a basic level of subsistence. It will require, at a minimum, an enhanced infrastructure of agriculture, transport, water and energy supply, waste disposal and pollution control. The population and its supporting infrastructure will need to be provided with stability through adequate protection against the consequences of environmental and manmade disasters, or institutional change. This growing demand for life-support systems coincides with increasing climate change, itself influenced, if not dominated, by human activity. As a result we have entered a period of intense global environmental change and the associated management problems will influence the geotechnical agenda of the future. Sustaining megacities, waste containment and protection from natural extreme events are three easily recognized examples.

Recognizing the need to focus more on sustainable development, Knill has identified eight aspects of the professional practice of engineering geology (read geotechnical engineering) that deserve greater attention:

- Work professionally and live in a manner which has a minimal influence on the environment, recognizing and mitigating impacts where they occur.
- Make use of environmentally friendly techniques using low cost and low quality materials, and "soft engineering".
- Give greater weight to the quantitative assessment of uncertainty and variability in assessing geological processes, and the properties of geological materials.
- Recognize the importance of geological processes within the context of time, and in relation to causation through other environmental mechanisms.
- Increase the extent to which modelling is used as a predictive and verifying tool.
- Accept that engineering geology (read geotechnical engineering) works for the benefit of people, and so needs to be related closely to the population affected by, or benefiting from, development.
- Give parallel recognition to the role of other disciplines in the assessment of the environmental issues.
- Understand the role of environmental legislation, regulation and policy formulation.

The geotechnical agenda of the future will be dominated by finding engineering solutions to problems which are responsive to environmental needs.

7.0 WHAT ARE THE CHALLENGES?

It would be satisfying to be able to state with confidence that the geotechnical community will evolve from its considerable record of achievement in the past and will deal effectively with the problems of the future. However, I do not believe that we can take comfort in this optimistic perspective. A number of issues must be recognized and dealt with before we can, as a professional community, look forward with confidence.

7.1 Inadequate Performance

In geotechnical engineering, as in other aspects of engineering, the overriding obligation requires that the constructed entity or process fulfill its intended function. It should normally do so in a safe, economic and environmentally acceptable manner. Successful performance requires meeting criteria of safety, serviceability, environmental acceptability and affordability. While the geotechnical engineer has a long tradition of success in meeting these requirements under conditions that differ from many other types of technological endeavours, there are some areas of application where inadequate performance remains distressingly frequent.

Unsuccessful performance might involve failure, excessive leakage or deformation, non-compliance with environmental requirements or other regulatory restrictions and excessive cost. In some instances unsuccessful performance might be judged in a broader social and environmental context. There are too many examples of unsuccessful performance in geotechnical engineering.

Morgenstern (1998) listed eleven serious incidents over the period 1995-1998 associated with mine tailings and waste overburden management. Others have occurred since then. All were involved with modern structures and were not part of the historical legacy of poorly engineered waste containment structures that characterized parts of the mining industry in the past. The consequences of these incidents were variable. There were a few fatalities and typically substantial environmental and economic penalties. There was no common element geographically or socio-economically. However each case involved geotechnical input from consultants well-known by either national or international standards. He concluded that "…..a well-intentioned corporation employing well-qualified consultants is not adequate insurance against serious incidents".

Hoek and Palmieri (1998) have provided valuable insight into the impact of geotechnical risk on large civil engineering projects. Unforeseen geological conditions and the associated geotechnical problems are a major contributor to cost and schedule overruns on large civil engineering projects. They cite a study of 71 hydroelectric projects financed by international agencies where estimated costs and schedules were compared with actual (World Bank, 1996). The study concluded that construction costs for hydropower projects were on average 27% higher than estimated. Experience indicates that less than 1% of the total project cost is spent on pre-engineering studies, which is remarkably low. Hoek and Palmeiri (1998) observed that a number of projects have actually been abandoned or have encountered costs and schedules that have escalated to several times the original estimate. They note that unforeseen geological conditions cannot be blamed for all of these costs and schedule overruns. However, many of these instances of unsuccessful performance are the result of inadequate geological data, inappropriate interpretation of available data and incompetence in dealing with the problems once they have arisen.

An excessive number of projects exhibiting unsuccessful performance, as defined above, is not restricted to the hydropower industry. Geotechnical engineering, as a whole, must strive to improve its record in this regard.

The ten year international programme of the International Decade for Natural Disaster Reduction (IDNDR) came to an end on December 31, 1999. During the decade important activities were conducted worldwide in order to implement the specific objectives of United Nations General Assembly Resolution 44/236, adopted in December, 1989. These activities involved agencies both within and outside of the UN system. While successor arrangements to IDNDR are being put in place at the international level, the decade ended with cruel reminders of ongoing challenges associated with preparedness and mitigation of natural disasters.

Between December 1-16, 1999 rainfall in Venezuela was eight times the usual amount for that time of year. As a result, in many areas of the Cerro Avila (the mountains that surround Caracas and its neighbouring states) landslides caused severe mud and debris flows that buried entire villages and affected a total of eight states, including Caracas. The 1999 Venezuelan disaster was not only the worst tragedy in Venezuela's history, but also one of the most severe disasters in the Americas in this century. The decade also ended with severely damaging earthquakes in Taiwan and Turkey, to remind us of the concerted effort needed to mitigate the consequences of seismic hazards.

It will be necessary for the geotechnical community to be more pro-active in multi-disciplinary undertakings in the future if the technical advances made in recent years are to have appropriate social and economic impact.

7.2 Inadequate Compensation

The ability to attract talented new people into our profession and retain those already contributing to it is closely linked to remuneration. There are no international statistics to guide a comparison between geotechnical engineers and others to assess this issue and therefore we must make use of national studies, where available.

The information presented in Figure 4 is disquieting (Davis, 2000). This is a plot of median income by major branch of engineering for 1998 according to the U.S. National Society of Professional Engineers (NSPE) "1999 Professional Engineer Income and Salary Survey". The figures for median annual income represents salaries, fees, cash bonuses and commissions received from respondent's primary jobs as reported on January 1, 1999, excluding any overtime pay. Of the 7,966 MSPE member respondents to the 1999 survey, 74.1% had supervisory or management responsibility and about 82.1% were registered engineers. Additional information on the survey may be found at the NSPE web site (www.nspe.org/em1-ssal.asp).

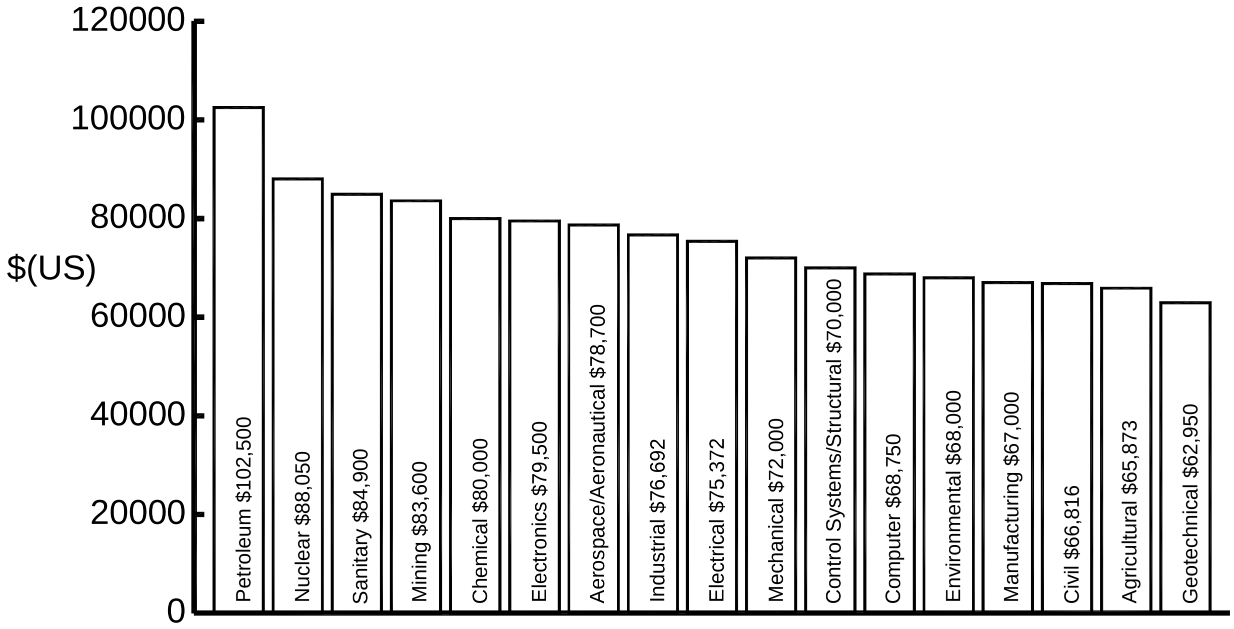

Figure 4. Median income by major branch of engineering.

This information reflects remuneration in the USA. Both absolute and relative remuneration levels will vary from nation to nation. It is the relative position of geotechnical engineers on the figure that is troubling. We are the lowest!

The factors affecting remuneration level are complex. Certainly supply and demand of professionally qualified manpower is one important consideration. Is there an over-supply? Remuneration tends to correlate with the real or perceived value added by the engineer. Does the fee structure in geotechnical engineering, which ultimately controls remuneration, reflect a perception of low value-added contributions? Has the bulk of geotechnical practice become routine, amenable to control by standards and gone the way of conventional materials testing?

7.3 Inadequate Recognition?

The natural materials that the geotechnical engineer must deal with are complex and do not afford the luxury of replication. Geotechnical undertakings, either in-situ or associated with unit construction processes themselves, are performed under circumstances very different from the controlled environment of a manufacturing plant. The implications of uncertainty, with examples of unsuccessful behaviour in geotechnical practice, are discussed at length by Morgenstern (2000).

The value-added component of geotechnical engineering is closely linked to performance assurance. When it goes wrong the penalties are severe for all involved. The complexity of performance assurance in geotechnical engineering has been underestimated and this requires greater recognition. To assure performance, comprehensive risk management tools must be applied and appropriate rewards are deserved when they are applied correctly.

Risk management can only be successful if critical sources of uncertainty are understood. This aspect of geotechnical engineering cannot be made routine. As emphasized by many commentators, judgment is essential to assure geotechnical performance. The need to apply the observational method is well-recognized, but its limitations are sometimes underestimated. Morgenstern (2000) has advocated the systematic application of qualitative and consequential risk analysis to the design and control of geotechnical projects. This application provides structure to the judgment process, makes it more transparent and facilitates risk management. This part of a project development requires the highest level of experience. It should be recognized as adding the highest value and rewarded accordingly.

8.0 ADDING VALUE THROUGH GEOTECHNICAL ENGINEERING

8.1 Introduction

The following examples, taken from personal experiences, are intended to illustrate how geotechnical engineering adds value to both industrial and social institutions. Other commentators will have comparable examples.

8.2 Adding Value in Synthetic Crude Oil Production

Synthetic crude oil is the product of the Alberta oil sands industry. The Alberta oil sands, located primarily in north eastern Alberta, comprise a vast resource of hydrocarbons. Of the 270 billion m^3 (1,700 billion bbls) contained in these Cretaceous deposits, less than about 10% are within the surface-mineable region, in the vicinity of Fort McMurray, Alberta. Estimates suggest that about 60% of the surface-mineable deposits are recoverable with current technology. While small as a percentage of the total resource, this nevertheless represents a huge recoverable reserve.

Commercial mining and processing of oil sands was pioneered by Suncor Ltd. (originally Great Canadian Oil Sands). The original mining scheme required removal of overburden, followed by mining with bucket-wheel excavation operating on a three-bench mining configuration. Suncor began operations in the mid-1960's. Bucket-wheel excavation has now been abandoned in favour of a high capacity truck and shovel operation.

Slightly more than a decade later, in 1977, Syncrude Canada Ltd. came on stream. At Syncrude, annual production is currently targeted at about 14.5 million m^3 (90 million bbls) of synthetic crude oil and, together with Suncor's production, represents in excess of 20% of Canada's petroleum needs. The industry is profitable and in the midst of aggressive expansion involving an investment of many billions of dollars.

Geotechnical engineering has contributed to the emergence of this successful industry in a number of ways, primarily related to safe mining practice involving slope stability concerns in a complex geological setting and to safe waste management systems involving enormous volumes of waste overburden, tailings and water. Morgenstern, Fair and McRoberts (1988) and Morgenstern (1996) provide technical details.

Reference to the Syncrude Canada operation provides some insight into the geotechnical contributions. This mine presently moves about 1,000,000 tonnes of material per day. The geology is complex and includes a large number of geotechnically challenging materials. The clay shale overburden has numerous weak presheared layers which cause foundation and slope instabilities. The oil sands straddle the boundary between hard soils and weak rocks, and contain many weak dipping clay layers that govern geotechnical performance. Some of the largest structures in the world have been created in order to store the tailings. Multiple mining and tailings management methods are used in an environment of continuous improvement.

McKenna (1998) recently reviewed the role of Syncrude's Geotechnical Review Board and summarized many of the geotechnical issues confronted by Syncrude and their consultants. The list illuminates the role of geotechnical engineering in this industry. It includes the following:

- dam construction on muskeg foundation
- spillway design and maintenance on weak valley slopes
- heavy foundation on gassy and temperature-sensitive soils
- coring and testing of gassy/expansive oil sands
- haul roads and trafficability for large mining equipment on oil sands
- depressurization of gassy watersand aquifers
- failure of starter dykes and movement of tailings dykes on clay shale foundations
- highwall design utilizing locked sands
- winter construction of large fluid retaining embankments
- design of landfills and sewage treatment plants
- frost effects on foundations and stockpiles
- short and long-term excavations into clay shale slopes
- cold-weather construction of tailings storage
- blockslides along inclined clay layers
- progressive failure in sands and clays
- empirical highwall monitoring for draglines
- highwall failures due to gas-exsolution and bulging
- pit floor heave
- concerns of static liquefaction of loose tailings sands
- use of lean oil sand as a construction material
- ore stockpile failures on weak clay layers
- characterization and management of fluid fine tailings
- failure of in-pit dumps due to collapse of clay shale fills
- movement and failure of out-of-pit dumps on clay shale
- long-term physical stability of reclaimed landscape

The successful application of geotechnical engineering to the oil sands industry has relied on a number of contributions including: 1) basic property studies, 2) advanced analytical studies, 3) geophysics, 4) instrumentation. But above all, there has been an intimate interaction between the analysis of the geological environment and geotechnical behaviour, with on-going application of the observational method.

Value has been added not by the separate application of soil mechanics or rock mechanics or engineering geology but by their integration, needed to bring a comprehensive geotechnical perspective to problem-solving.

8.3 8.3 Adding Value by Saving Lives

On 25 August, 1976, soon after 10:00 a.m., the fill slope immediately behind Block 9 of the Sau Mau Ping Estate in Hong Kong failed. The resulting mud avalanche buried the ground floor of the block killing eighteen people. This disaster had wider implications because 71 persons were killed in a slope failure, also in fill and also at Sau Mau Ping in 1972. The Final Report of the Commission of Inquiry concluded, with regard to the 1972 failure, that no fault was found "with the manner in which the design and construction of the embankment was carried out". Since the 1976 failure made this conclusion suspect, the Government of Hong Kong appointed an Independent Review Panel on Fill Slopes to advise on the cause and implications of the 1976 Sau Mau Ping failure. In retrospect, this proved to be a major turning point in the evolution of geotechnical engineering in Hong Kong.

The Panel was tasked to report on the following:

a) the cause of the recent failure
b) assessment of risk of further failure on the recently failed slopes and in other fill slopes which may affect public housing estates

c) feasibility of temporary and permanent remedial works for the recently-failed slopes
d) assessment of risk of failure in fill slopes elsewhere taking account of past design and construction practice in Hong Kong
e) recommendation on design of future fill slopes.

The Panel, with the assistance of others, recognized that the 1976 slope failure was the result of infiltration during intense rainfall in end-tipped loose fill, followed by loss of strength and consequent conversion of the upper few metres of the fill into a destructive mud avalanche. Loose fill was found in many other slopes in Hong Kong, and a program of re-compaction of the surface layer of fills was recommended. Improved specifications were to be adopted for the design and construction of future fill slopes. Finally, the Panel recommended "that a control organization be established within the Government to provide continuity throughout the whole process of investigations, design, construction, monitoring and maintenance of slopes in Hong Kong".

The Government of Hong Kong accepted the recommendations. Compaction of old fill slopes has been an on-going remediation programme. A recent review by the Hong Kong Geotechnical Engineering Office has confirmed its effectiveness while observing that other methods of mitigation may be attractive under special circumstances.

The Government also established the Geotechnical Control Office (GCO) which later became the Geotechnical Engineering Office (GEO). This organization has generally worked under the remit suggested by the Review Panel, but at a scale much greater than originally envisaged. Under the leadership of a series of distinguished Directors, it has grown to be an internationally recognized centre of excellence.

The Mission Statement of the GEO is as follows:

"We will meet Hong Kong's needs for the highest standard of slope safety and engineering development through:

- excellence in geotechnical practice
- partnership with the community and the profession
- the dedicated teamwork of all of our staff".

The basic mandate of GEO resides in enhancing public safety. This is recognized in Government policy statements that sets out targets for overall landslide risk reduction. Current policy estimates that by 2010 the overall landslide risk associated with man-made slopes will be below 25% of the level in 1977.

Hong Kong has a population of some 7 million within a land area of only 1,097 square kilometers. The terrain is hilly, with steep slopes, mantled by residual soils. The rainfall averages 2.225 m annually and more than 80% of this falls during the period May to September. Intensities can be high, with 50 mm/hour and 200 mm in 24 hours being not uncommon. Landslides are frequent during or immediately after periods of intense rainfall.

Figure 5 (Chan, 2000) summarizes data on known landslip fatalities in Hong Kong. Notwithstanding the extraordinary growth in Hong Kong since 1976, the improved record is indisputable. Not only has public safety been improved by the slope management team, but property values have also been enhanced, although data in this regard is not readily available.

There is an extensive technical literature describing ground characteristics and geotechnical evaluation applied to slope engineering in Hong Kong (e.g., Brand, 1985; Li, Kay and Ho, 1998). There is no need to repeat any of this material here. Instead, the following summarizes some of the main concepts, integrated over the years, that underpin the slope management system in Hong Kong.

At the outset, GEO began the creation of a slope catalogue. Airphoto interpretation was employed and has remained a dominant technique in catalogue development. Site inspections assisted the establishment of priorities for slope up-grading. Relative risk considerations were applied early in the development of the up-grading priorities. Studies into rainfall-landslide correlations formed the basis of a landslide warning system and the beginning of a substantial effect on rainfall monitoring. This was a major advance in risk communication. It is one thing to discuss warning systems theoretically; it is another to implement them successfully with the general public.

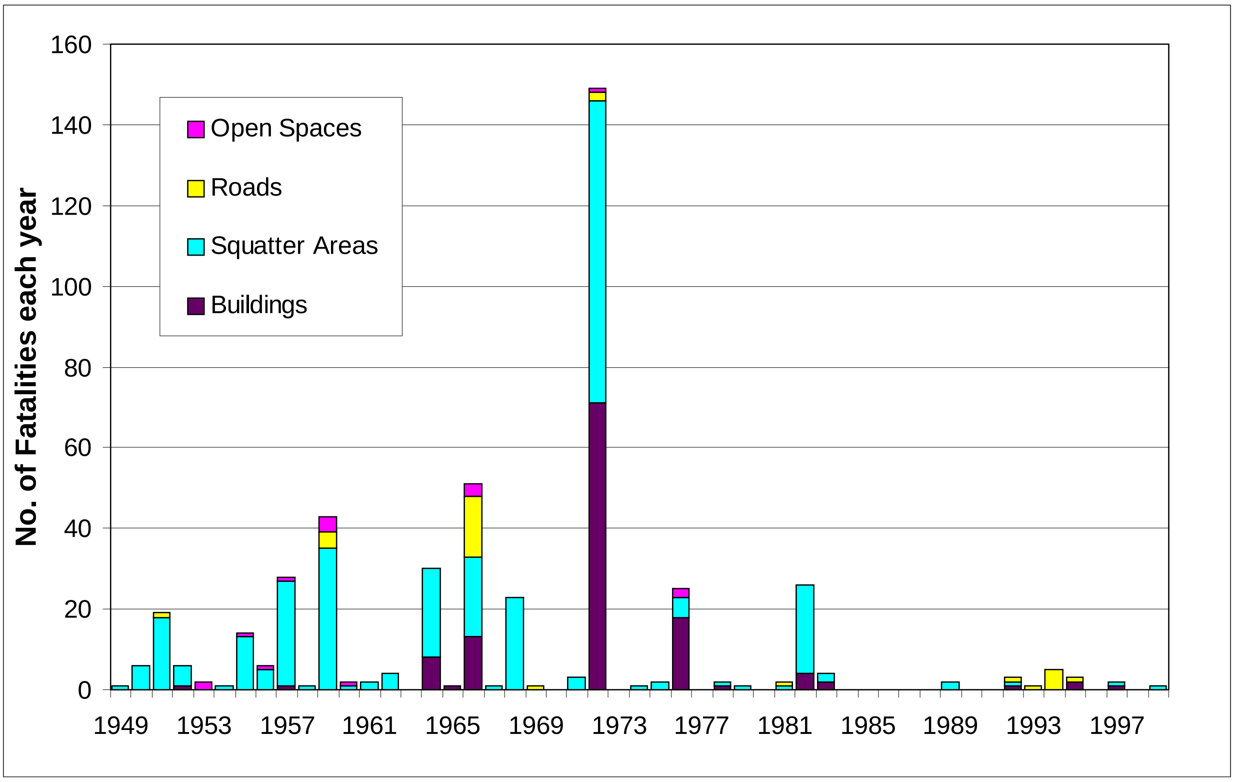

Figure 5. Known Landslip Fatalities in Hong Kong (Chan, 2000)

Through the early 1980's, GEO sponsored a number of terrain evaluation studies integrating terrain analysis, engineering geological assessment and geotechnical evaluation as background for land use considerations. Early programs were also directed at improved understanding of unsaturated soil behaviour in both the laboratories and the field. The significance of relict joints and clay seams were detected, blurring the boundaries between soil and rock mechanics. The Mid-levels Study of 1982, a major study influencing development in an important part of Hong Kong, shows clearly that geology, geomorphology, hydrogeology and geotechnical characterization were being integrated, at least at the level of major studies.

As illustrated by Figure 5, a large number of fatalities were due to slope stability problems in areas of illegal squatters. The hazard had been recognized earlier, but there had been administrative reluctance to face up to the issue of forced re-settlement. Enhancing public safety is not achieved by technical considerations alone. After 1982, there was increased efforts to remove illegal squatters from dangerous areas.

Through much of the 1980's the emphasis at GEO was on engineering and regulations. Figure 5 illustrates that following 1982 there were few, if any, events to elicit public concern. In retrospect, this may have coincided with a period of below-average rainfall.

In 1992 a fatal landslide occurred at Baguio Villas that was attributed to lack of maintenance of drainage systems. This created a heightened awareness of the need to give guidance on and promote slope maintenance as an integral part of the slope safety system.

Heavy rain in 1993 created a number of debris flows in Lantau Island highlighting the need to devote more resources to natural slope hazards. Risk analysis considerations began to be explored.

The Kwun Lung Lau landslide in 1994 resulted in five fatalities and more injuries. This landslide provoked considerable public concern in Hong Kong and resulted in technical detailed inquiries by the GEO (Hong Kong Government, 1994; Morgenstern, 1994). The Kwun Lung Lau landslide involved a slope and retaining wall that had been catalogued, a configuration that had been subjected to a preliminary study and assessed as adequate, a site that had been inspected periodically by qualified consultants, even shortly before the unfortunate occurrence and had occurred when the landslide warning was in effect. Hence questions were raised with regard to the effectiveness of the whole risk management system. Detailed studies revealed that the landslide occurred as a result of sub-surface infiltration from defective buried drainage systems. Inaccurate historical documents describing the retaining wall at the site were misleading and likely resulted in inadequate appreciation of the potential risk at this site. Human uncertainty dominated the failure as opposed to more traditional geotechnical consideration Hong Kong has implemented programs to avoid these specific causes in the future.

GEO is charged with up-grading many existing man-made slopes over the next decade while encouraging measures to enhance stability of existing slopes. This has required a considerable investment into information technology (slope information systems), enhanced design and construction productivity, use of risk analysis and increased emphasis on community preparedness and response. There is also increased public pressure to enhance aesthetics of slopes. The move to "social engineering" is particularly illustrative of the range of activities required to develop an effective slope safety system. Details are given by Yim, Lau and Massey (1999).

Table 1 (Malone, 1998) summarizes the components of the Hong Kong slope safety system. Are they soil mechanics or rock mechanics or engineering geology? They are all and more. GEO adds value in meeting its objectives, consistent with its mission statement, by integrating all aspects of geotechnical engineering together with additional non-technical tools required for effective risk management in a public setting.

Table 1. The slope safety system (Malone, 1998)

	Contribution by Each Component		
Slope Safety System Components	**To Reduce Landslip Risk**		**To Address Public Attitudes**
	Hazard	**Vulnerability**	
Policing			
Cataloguing, safety screening, and statutory repair orders for slopes	√		
Checking new works	√	√	
Maintenance audit	√		
Inspecting squatter areas and recommending safety clearance		√	
Input to land use planning	√	√	
Safety standards and research	√	√	√
Specialist works projects			
Upgrading old Government slopes	√		
Preventive works for old tunnels	√		
Education and Information			
Maintenance campaign	√		√
Personal precautions campaign		√	√
Awareness Programme	√	√	√
Information Services	√	√	√
Landslip Warning and emergency services	√	√	√

8.4 Adding Value in Hydro-electric Production

The Sainte-Marguerite-3 (SM3) hydroelectric project, currently under construction, is located 90 km north west of Sept-Isles, in the north-eastern part of the Province of Québec. The site develops a total head of 330 m over the eight km separating the powerhouse from the reservoir. The development involves construction of the following works:

- a 171 m high earth and rock fill dam that required construction of a 978 m long diversion tunnel and the construction of a 20 m high upstream cofferdam.
- an 8 km headrace tunnel
- a three unit underground powerhouse with an installed 2 unit capacity of 882 MW
- a three gate spillway

The main civil works are essentially complete and the power station is expected to come into service in 2001. Impounding began in 1998. A number of technical papers have been published (Rattue et al., 2000; de Courval et al., 1998).

The region in which the SM-3 project is situated is generally rugged terrain with narrow valleys. It forms part of the Canadian Shield. The rock is primarily gneisses, intruded locally by anorthosite, granite and pegmatite. The majority of the works at SM3 are in an anorthosite batholith, a high quality rock. Seismicity is only moderate. The dam site is characterized by a narrow, steep-sided valley. Bedrock outcrops principally at the cliffs at the top of the left abutment and sporadically on the right abutment.

Site investigation was undertaken over several years, involving seismic refraction surveys, overburden and bedrock drilling, terrain analysis and geological synthesis. Major features identified by the investigation program were the deep alluvial deposits in the river and the generally steep form of the bedrock at the abutments beneath the talus.

In order to accommodate the optimal location of the dam, it was necessary to construct a 20 m high upstream cofferdam in the v-shaped canyon filled with 20 m of loose sand underlain by 40 m of coarse alluvium. Seepage calculations indicated the need for a positive cutoff wall. The wall was formed by a primary row of columns through both formations and a secondary row of columns through the coarse alluvium. The cutoff wall reached a maximum depth of 65 m, a world record, and performed well under a head of over 40 m. Elsewhere beneath the cofferdam blast densification of the sand was utilized to enhance stability.

The dam is a central earth core rock-fill structure with external slopes of 1.75:1 upstream and 1.65:1 downstream. Due to the steep valley slopes and roughness of the rock profile, foundation preparation and grouting were challenging.

The materials for the dam incorporate till for the core, natural sand filters obtained from the foundation sand excavation and crushed rock for the transitions and shells. All are within precedent at Hydro-Québec. Instrumentation has been installed both for routine monitoring and to observe special features such as the downstream crowding of equipotential lines, observed in a number of dams all over the world. Advanced analyses were used to assist in the decision to incorporate a large slide mass in the downstream shell of the dam.

Rock conditions for the underground works were generally excellent. In-situ stress measurements, stress analysis, rock reinforcement, geological mapping and rock monitoring were all incorporated in the design and construction of the underground works. It should be noted that the headrace tunnel and approach to the underground powerhouse are unlined and will operate under a peak pressure of 3-6 Mpa which stretches experience in Canada.

While details at SM-3 are unique, it is characteristic of many large hydroelectric projects in illustrating the value added by geotechnical engineering. Many decisions are taken both during design and construction that involve risk. While specialist skills are important inputs, the geotechnical contribution to risk management requires an integration and overview in order to be constructive.

8.5 Commentary

The examples presented here illustrate that geotechnical engineering goes beyond its building blocks, illustrated in Figure 1, in order to add value. The extra value arises from the synergy associated with understanding earth materials and earth processes regardless of consistency and origin. This maybe self-evident to many, but it is not reflected adequately in most academic programs and the structure of many industrial and research organizations. Perhaps most important of all, it is not reflected in the organizational structure that our profession presents to the rest of the scientific and technological world.

9.0 TOWARD AN INTERNATIONAL GEOTECHNICAL UNION

Geotechnical engineering has much to contribute to both current and future industrial and environmental needs, particularly within a context of sustainable development. The strength of geotechnical engineering resides in its integrated and holistic approach to the engineering of earth materials and processes in the face of considerable uncertainty. Experience has led to comprehensive risk management procedures and they continue to evolve. Geotechnical engineering is synergistic in that the whole is greater than the sum of its parts.

The capabilities of geotechnical engineering will be under-utilized, under-valued and under-rewarded unless an organizational structure emerges to promote the integrated prespective espoused here. The current structure of separate societies, (ISSMGE, ISRM, IAEG) is incapable of assuming this role. They have their own mandates and are fully occupied in fulfilling them. Nevertheless the existing societies would have supporting roles in any new organization.

This inquiry into "Common Ground" leads me to the conclusion that a new organization is needed, an International Geotechnical Union (IGU). An international union is not only a union of other international societies, but also a union of nation societies or committees. In many countries a single geotechnical society already exists and for the IGU to be formed merely requires agreement of these national societies. Where no single representing body exists, an effort would have to be made to form one. The existing international associations would act as affiliated or supporting organizations. IAEG, ISRM and ISSMGE are already affiliated with the IUGS.

The International Union of Geodesy and Geophysics (IUGG) or the International Union of Geological Sciences (IUGS) present equivalent models. At the IUGG 22nd General Assembly in 1999 there were Union lectures and Union Symposia, Inter-Association Symposia and Workshops and Association Sessions. Seven International Associations affiliate with IUGG such as the International Association of Hydrological Sciences (IAHS) and the International Association of Seismology and Physics of the Earth's Interior (IASPEI).

The IGU would promote the integrated perspective of geotechnical engineering in education, research, and practice. Participation in the International Council for Science (ICSU) may be of value.

Building on the success of Geo Eng 2000, the proposed Union would convene Geo Eng 2004.

To form the IGU, the following will be necessary:

1) national societies should study the concept and support the formation of the Union
2) international societies should agree to support the Union and affiliate with it
3) a national society should propose the hosting and organization of Geo Eng 2004
4) the formal creation of the IGU should take place at Geo Eng 2004.

10.0 CONCLUSIONS

Geotechnical Engineering has a proud record of application of the sciences of soil mechanics, rock mechanics, engineering geology and other related disciplines to the resolution of numerous development and environmental problems. Value-added contributions arise more from the integrated perspective of geotechnical engineering than from one of its specialized components alone. A new organizational structure is needed to promote this perspective. The formation of the International Geotechnical Union is proposed to meet this objective.

11.0 ACKNOWLEDGEMENTS

I appreciate the stimulating discussions with David Cruden on several of the themes within this presentation.

12.0 REFERENCES

Anon (1999). "Definition of geotechnical engineering". *Ground Engineering*, Vol. 32, No. 11, p. 39.

Arnould, M, (1970). "The International Association of Engineering Geology History". *Bulletin of the International Association of Engineering Geology*, No. 1, p. 22-28.

Brand, E.W. (1985). "Predicting the performance of residual soil slopes". (Theme Lecture) Proceedings of the 11th International Conference on Soil Mechanics and Foundation Engineering, San Francisco, Vol. 5, p. 2541-2578.

Burwell, E.B. and Roberts, G.D. (1950). "The geologist in the engineering organization". In "Application of Geology to Engineering Practice" ed. by S. Paige, Geological Society of America, p. 1-10.

Chan, R.K.S. (2000). "Hong Kong slope safety management system". Proceedings of the Symposium on Slope Hazards and Their Prevention, The Jockey Club Research and Information Centre for Landslip Prevention and Land Development, The University of Hong Kong, p. 1-16.

de Vourval, P., Grenon, A. and Nguyen, D. (1988). "The SM-3 power project: a case history of large underground excavations". *Canadian Tunnelling*, p. 17-25.

Davis, R. (2000). "Engineer's income outpaces inflation by 3%". *Geotechnical Fabrics Report*, Vol. 18, p. 30-31.

Engineering News Record (1999). "125 years of top projects". *Engineering News Record*, Vol. 243, No. 4, p. 41-72.

Fookes, P.G. (1997). " Geology for engineers: the geological model, prediction and performance". *Quarterly Journal of Engineering Geology*, Vol. 30, p. 293-424.

Geotechnical Engineering Office (1994). "Report on the Kwun Lung Lau landslide of 23 July 1994". 2 Volumes, Geotechnical Engineering Office, Hong Kong.

Goodman, R.E. (1999). "The Engineer as Artist". *ASCE Press*, Reston, Virginia.

Hoek, E. and Palmieri, A. (1998). "Geotechnical risks on large civil engineering projects". Proceedings 8th International Congress; International Association of Engineering Geology, Vol ??, p. 79-88.

Kiersch, G.A. (199)1. "The heritage of engineering geology; Changes through time". *The Heritage of Engineering Geology; The First Hundred Years*, ed. by G.A. Kiersch, Centennial Special Volume 3, Geological Society of America, p. 1-50.

Knill, Sir J. (1997). "Environmental change and engineering geology: our global change". Proceedings International Symposium on Engineering Geology and the Environment, International Association of Engineering Geology. Balkema, Vol. 4, in press.

Lapworth, H. (1911). "The geology of dam trenches". *Transaction Association of Water Engineers*, Vol. 16, p. 25.

Legget, R.F. (1962). "Geology and Engineering". 2nd Edition, McGraw-Hill.

Li, K.S., Kay, J.N. and Ho, K.K.S. (1998). "Slope Engineering in Hong Kong". Balkema.

Lugeon, M. (1933). "Barrages et Géologi"e. Librairie de l'Université, F. Kouge et Cie, Lausanne.

Malone, A.W. (1998). "Risk management and slope safety in Hong Kong". In *Slope Engineering in Hong Kong*, ed. by K.S. Li, J.N. Kay and K.K.S. Ho. Balkema, p. 3-17.

Martin, C.D. (1997). "Seventeenth Canadian Geotechnical Colloqium; The effect of cohesion loss and stress path on brittle rock strength". *Canadian Geotechnical Journal*, Vol.34, p. 698-725.

McDonald, C.W. (1915). "Some engineering problems of the Panama Canal in their relation to geology and topography". *U.S. Bureau of Mines*, Bulletin No. 86.

McKenna, G. (1998). "Celebrating 25 years, Syncrude's Geotechnical Review Board). *Geotechnical News*, Vol. 16, No.3, p. 35-41.

Morgenstern, N.R. (1994). "Report on the Kwun Lung Lau Landslide". Vol. 1 - Causes of the Landslide and Adequacy of Slope Safety Practice in Hong Kong. Hong Kong Government.

Morgenstern, N.R. (1996). "Geotechnics and mine waste management". Proceedings of the International Symposium on Seismic and Environmental Aspects of Dam Design. Chilean Geotechnical Society, Santiago, Vol. 2, p. 5-25.

Morgenstern, N.R. (1998). "Geotechnics and mine waste management - an update". Proceedings of the Workshop on Risk Assessment and Contingency Planning in Tailings Management Systems, Buenos Aires, International Council on Metals in the Environment, p. 171-175.

Morgenstern, N.R. (2000). "Performance in geotechnical practice". The First Lumb Lecture. *Transactions of the Hong Kong Institution of Engineers*, in press.

Morgenstern, N.R., and Cruden, D.M. (1997). "Description and classification of geotechnical complexities". Proceedings of International Symposium on The Geotechnics of Structurally Complex Formations, Italian Geotechnical Society, Vol. 2, p. 195-204.
Morgenstern, N.R., Fair, A.E. and McRoberts, E.C. (1988). "Geotechnical engineering beyond soil mechanics: a case history". *Canadian Geotechnical Journal*, Vol.25, p. 637-661.
Müller, L. (1967). "Addres". Proceedings First Congress of the International Society of Rock Mechanics, Lisbon, Vol. 3, p. 90-92.
Müller, L. (1979). "Josef Stini: Contributions to engineering geology and slope movement investigations". *In Rockslides and Avalanches*, Vol. 2, ed. by B. Voight, Elsevier, Amsterdam, p. 95-109.
Paige, S. (1950). "Application of Geology to Engineering Practice". *The Berkey Volume*. Geological Society of America.
Rattue, D.A., Hammamji, Y. and Tournier, J.-P. (2000). "Performance of the Sainte Marguerite-3 dam during construction and reservoir filling". Transactions 20th International Congress on Large Dams, Beijing, Question 78, in press.
Redlich, K., Terzaghi, K., and Kampe, R. (1929). *Ingenieurgeologie*. Julius Springer, Wien.
Rocha, M. (1967). "Address" Proceedings First Congress of the International Society of Rock Mechanics, Lisbon, Vol. 3, p. 68-70.
Stini, J. (1922). "Technische Geologie". F. Encke, Stuttgart.
Terzaghi, R.D. and Voight, B. (1979). "Karl Terzaghi on rock slides: the perspective of a half-century". In *Rockslides and Avalanches*, Vol. 2, ed. by B. Voight, Elsevier, Amsterdam, p. 111-133.
Terzaghi, K. (1925). "Erdbaumechanik auf Bodenphysikalischer Grundlage", Franz Deuticke, Wien.
Terzaghi, K. (1929). "Effect of minor geological details on the safety of dams". *American Instititution of Mining and Metallurgy*, Technical Publication No. 215, p. 31-44.
Terzaghi, K. (1957). "Opening session". Proceedings Fourth International Conference on Soil Mechanics and Foundation Engineering, London, Vol. 3, p. 55-58.
Terzaghi, K. (1963). "Discussion of "An approach to rock mechanics" by K. John. Proceedings American Society Civil Engineers, *Journal of Soil Mechanics, Foundation Div*., Vol. 89, p. 295-300.
The World Bank (1996). "Estimating construction costs and schedules - experience with power generation projects in developing countries". World Bank Technical Paper No. 325.
Yim, K.P., Lau, S.T. and Massey, J.B. (1999). "Community preparedness and response in landslide risk reduction". Proceedings of the Seminar on Geotechnical Risk Management in Hong Kong, Honk Kong Institution of Engineers, P. 145-155.
Zaruba, Q. (1970). "Engineering geology, some experiences and considerations". *Bulletin of the International Association of Engineering Geology*, No. 1, p. 15-21.
Zaruba, Q. and Mencl, V. (1963). "Engineering Geology". Elsevier, Amsterdam.