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Engineering geology for the New Millennium: Stick with the basics

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ABSTRACT

Our experience indicates most problems and difficulties in geotechnical practice result from failure to apply available information, existing knowledge, and well-established project development procedures. Many, if not most, of these problems and difficulties result from failure to apply in an organised manner basic concepts and techniques of engineering geology.

Future challenges and opportunities are outlined with emphasis on infrastructure projects in both developed and developing countries. Ten previously presented Fundamentals of Geotechnical Engineering Practice (geology, geometry, geomechanics, observation, imagination, common sense, precedents/experience, construction/constructability, communication, diplomacy) are updated and five new Fundamentals (history, field emphasis, checking, redundancy, flexibility) are added. All fifteen Fundamentals are focused on an observational engineering geology approach for developing the geotechnical framework of sites and problems.

For geotechnical practice in the twenty-first century, we have a simple message: Stick with the basics–traditional concepts and procedures including the fifteen Fundamentals.

INTRODUCTION

Our collective experience of more than fifty years in geotechnical engineering practice, primarily in the United States of America, indicates that problems and difficulties in this area of practice typically result from failure to apply available information and existing knowledge, including well-established project development processes, rather than failure to analyse precisely, use computers or other high technology, or implement the latest cutting edge research techniques. Many, if not most, problems and difficulties result from failure to apply in an organised manner basic concepts and techniques of engineering geology, e.g., Newman and Adams (1999). Similar general conclusions have been drawn by others with greater breadth and depth of experience, e.g., D'Appolonia and Shaw (1999), Feld (1968), Hoek and Palmieri (1998), Lemley (1999), Osterberg (1989), Peck (1973, 1997), Sowers (1993).

As we approach the New Millennium with its anticipated high level of geotechnical activity on new projects in developing countries in Asia and elsewhere as well as infrastructure rehabilitation projects in developed countries, it is appropriate to reflect on our experience in the United States and offer certain suggestions in the hope that some of the mistakes made here in the past can be avoided in the future.

An overview of challenges and opportunities for engineering geology and geotechnical engineering in the New Millennium is presented with emphasis on future areas of activity, "fast-tracking," new project delivery systems, and the benefits to be derived from Fundamentals. Next, ten Fundamentals of Geotechnical Engineering Practice (Hamel 1983) are reviewed and updated for the New Millennium. Then, we present five additional Fundamentals relevant to the practice of engineering geology and geotechnical engineering. Finally, we outline a basic observational engineering geology approach for developing the geotechnical framework of a site or problem.

CHALLENGES AND OPPORTUNITIES FOR THE NEW MILLENNIUM

Future areas of activity

Anticipated future areas of activity in both developed and developing countries offer great challenges and opportunities in engineering geology and the closely related fields of geotechnical and environmental engineering. In developing countries, there will be many new projects involving infrastructure, i.e., water supply and distribution, waste water collection and treatment, solid waste disposal, transportation, communication, energy production and distribution. Some of these countries will also experience considerable activity in petroleum production, mining and mineral extraction, and construction of manufacturing and commercial facilities and housing. All of this infrastructure and other development work must proceed compatibly with the new theme of sustainable development (James 1999).

There will also be some rehabilitation work in urbanised or previously developed portions of these countries. Other than this rehabilitation work and some infrastructure work, much of the future work in developing countries will be done in "greenfield" areas, i.e., areas without previous significant land use modifications, including construction/mining activities, urban or suburban development, or pollution/contamination. Work in both previously developed and "greenfield" areas of developing countries will provide numerous challenges and opportunities. In particular, work in "greenfield" areas will provide great opportunities to "get it right the first time" in terms of environmental impacts as well as investigation, design, and construction for efficient and economical long-term project operation. All of this work in developing countries will, of course, involve dealing with the natural hazards, e.g., landslides, earthquakes, floods, common to many of these areas.

Most of the future work in developed countries will occur in previously developed areas. In parts of certain developed countries, e.g., Greater Pittsburgh Region of United State, there will be more new projects than in recent decades and most of these will proceed in previously developed areas. Much of the other future work in developed countries will involve infrastructure rehabilitation with associated environmental impacts and mitigation. Many of the infrastructure projects will involve insertion of new components and facilities in urban areas with significant geometric, topographical, geological, environmental, cultural, and political constraints, e.g., Athens Metro (Marinos et al. 1997), Pittsburgh Airport Busway (Hamel et al. 1998a,b). These projects offer opportunities to correct certain previous problems but they also pose significant challenges regarding coordination, scheduling, and cost over-runs in urbanised areas with considerable public and political scrutiny.

Another aspect of future work in urban areas everywhere is the increasing use of sites passed over or avoided earlier, in many cases because of geological hazards and expensive geotechnical solutions to constructability. For example, the Greater Pittsburgh Region of the United States has many steep, undeveloped hillsides that were avoided previously because of difficult access, geological problems including landslides and rockfalls, and/or expensive geotechnical solutions, e.g., bored piles, anchored retaining walls. These hillsides, which comprise much of the open space remaining in the Pittsburgh area, are experiencing increasing development pressures (Hamel 1998b). Projects involving sites previously considered marginal, uneconomical, or even unbuildable will present additional future challenges and opportunities everywhere.

Fast-tracking

There is an increasing tendency to "fast-track" projects. On public works projects, this results largely from politically driven deadlines developed with little or no consideration of the times necessary for proper project development, i.e., planning, investigation, design phases, bidding or negotiation of contracts, construction. There is a widespread but generally mistaken notion that modern electronic technologies can overcome time constraints as well as deficiencies in organisation, planning, investigation, design, and construction.

"Fast-track" projects are not always thought through to the extent that they are well-planned or well-organised, particularly with regard to geological and geotechnical issues. The design process is an iterative one that typically involves several phases (e.g., preliminary, pre-final, final) for a complex project. Each design phase depends on the results of preceding investigations and design phases. Even with well-conceived "fast-track" projects, the processes of project development and design typically proceed before investigations are completed and construction usually begins before design is completed.

To date, the only advantage we have observed with "fast-track" projects is shortening the time to project completion. This typically requires more engineering and construction personnel time (often at premium rates for overtime) over a shorter period for a higher overall cost. "Fast-track" projects often sacrifice both efficiency and quality (in investigation, design, and construction) in order to meet a tight schedule. This sometimes leaves significant problems to be corrected later, e.g., through maintenance or rehabilitation activities.

The "fast-track" procedure might be efficient and economical if well-conceived and well-managed, but it is also prone to major problems (e.g., delays, cost over-runs) if things, for whatever reason(s), do not proceed according to plans. Unforeseen geological conditions and other geotechnical deficiencies can play havoc with "fast-track" endeavours.

New project delivery systems

Infrastructure and other projects worldwide are increasingly being developed with new forms of project delivery, e.g., design-build (DB) and design-build-operate-maintain (DBOM), which differ in many ways from the traditional project delivery procedure of design-bid-build (DBB). The traditional DBB procedure involves investigation, design, and production of bid documents by an engineer (or engineering organisation) on behalf of the owner. Contractors are then invited to bid on the work and generally the low bidder is selected by the owner, perhaps with some input and assistance from the engineer. After construction is completed by the contractor, usually with monitoring of the work by the owner and the engineer, the project is turned over to the owner to operate and maintain. With DB, engineers team with contractors (and perhaps others) for investigation, design, and construction of the project for the owner to operate and maintain. DBOM carries this process further with the team continuing to operate and maintain the project or facility for the owner.

The DB and DBOM approaches have some positive aspects. These include more accountability and involvement of the contractor in the design process (DB) and more involvement of both the engineer and the contractor in operations and maintenance (DBOM). Much of the recent interest in these approaches seems to result, however, from their use in "fast-tracking" projects. The primary interest with these approaches is often reduction of the time from project inception to completion. This compression of the project schedule can magnify problems in many areas, whatever the project delivery system.

Geological conditions and geotechnical deficiencies have long been known to cause delays, cost over-runs, and other problems with the traditional DBB form of project delivery where most of the financial and other results of these problems are ultimately passed on to the owner. Under alternate forms of project delivery, e.g., DB or DBOM, geological and geotechnical problems assume greater importance for the engineer, contractor, and other team members. The team members have a larger stake in the project outcome and can no longer pass the financial and other results of problems on to the owner as readily as with the traditional DBB system. These alternate project delivery systems, along with the above-mentioned "fast-track" procedures, provide additional challenges and opportunities for engineering geologists and geotechnical engineers.

Emphasis on fundamentals to maximise benefits

In view of all of the above, we strongly believe that greater benefits will be derived from emphasis on the Fundamentals of engineering geology and geotechnical engineering practice within well-established processes of project development than on most of the currently popular toys, fads, and paradigms including certain computer software, high technology devices, and "quality-oriented" management systems. Computers and other high technology devices offer great potential in engineering geology and geotechnical engineering but it must be remembered that the output is only as good as the input (Read 1998). In engineering geology and geotechnical engineering, the input must come from fieldwork by competent individuals well versed in Fundamentals.

Quality management finally reached the service industry of engineering in the early 1980s. Extensive amounts of time and money have been spent in this area over the past two decades by both the private and public sectors. Despite these efforts, the overall quality, i.e., conformance to requirements, in this area generally appears to be decreasing. This results from mis-applications and deficiencies in implementation, rather than deficiencies in the quality management systems themselves.

Our experience indicates that the mis-application of "quality-oriented" management systems all too frequently allows critical geological and geotechnical features to "fall through the cracks" because of haste, lack of attention to details, and organisational ignorance and indifference. The latter organisational deficiencies often include "lip service" rather than support, checking, and other follow-up activities by middle and upper management.

FUNDAMENTALS OF GEOTECHNICAL ENGINEERING PRACTICE-UPDATE

Hamel 1983 listed and discussed ten Fundamentals of geotechnical engineering practice which apply equally well to engineering geology and geological engineering:

- Geology
- Geometry
- Soil and Rock Mechanics (Geomechanics)
- Observation
- Imagination
- Common Sense
- Precedents or Experience
- Construction or Constructability
- Communication
- Diplomacy

The list was kept to ten items so they could easily be counted on the fingers of two hands and also for consistency with the Ten Commandments of Judeo-Christian religions. Our experience indicates these Fundamentals, which are interrelated, require continual emphasis. They will be reviewed below and updated for the New Millennium.

Most practitioners in engineering geology and geological engineering, along with many in geotechnical engineering, will agree that geology is of paramount importance. Work in all these areas involves earth materials, i.e., soil and rock, produced and subsequently modified by geological agents and processes. Geological/geotechnical practice is regional (or local) in nature as a result of regional (or local) geology. Site-specific geological conditions profoundly influence project-specific investigation, design, and construction. Glossop 1968 had a classic comment which always merits repeating: "If you do not know what you should be looking for in a site investigation, you are not likely to find much of value."

The importance of geology was clearly recognised by the pioneers in engineering geology and geotechnical engineering, e.g., Terzaghi (Goodman 1999), Peck (Dunnicliff and Deere 1984), Skempton (1966), Legget (1979), Muller (1988). Some of us have been fortunate enough to develop this geological perspective early in our careers. Other geotechnical engineers, heavily trained in laboratory and/or analytical techniques early in their careers, come to recognise the importance of geology later, e.g., Henkel (1967, 1982), D'Appolonia and Shaw (1999). These anecdotal examples suggest that geotechnical engineers who do not initially recognise the importance of geology may come to appreciate it more as they mature.

Geometry, the spatial relationship and measurement of things, is fundamental to both geology and engineering. In geotechnical work, geometry includes topography; the location, size, shape, fabric, and texture of zones of geological materials and their discontinuities; and the size, location, and configuration of project features. Geometry, along with geology, defines the geotechnical framework of a project or problem. (History, discussed in the next section, is also an important component of the geotechnical framework of most projects and problems.)

Unless the geotechnical framework of a project or problem is properly defined, inappropriate materials are sampled and tested, inappropriate models are analysed, and the results are meaningless. Where the geotechnical framework is truly understood and appreciated, it is often possible, with the guidance of concepts and theories of geomechanics and geohydrology, but without detailed analyses, to predict or anticipate important behavioural aspects on the basis of observation, imagination, common sense, and precedents. Where detailed analyses are required, they must be focused on appropriate features of the geotechnical framework.

Despite the great advances in surveying and computer technologies in recent years, we find that the quality and quantity of information focused on both the geological and geometric components of the geotechnical framework of many projects in the United States is actually decreasing. This seems to result from a loss of field emphasis (going out in the field to look at things) by engineering geologists and geotechnical engineers and a general decline of their skills in surveying, field methods (including geological and topographical mapping), and graphical communications (including sketches, maps, plans, and cross-sections). Where personnel are sent to the field to obtain geological and geometric data, they are often the least experienced (i.e., least expensive) people available and they are sent out with little or no guidance by senior (presumably experienced) personnel.

There is also a lack of appreciation for the critical aspects of geometric components, particularly in previously developed areas and on "fast-track" projects. Even where geometric discrepancies have been discovered on multi-million dollar public works projects, design has continued with the wrong geometry to satisfy schedule and budget requirements (Fig. 1).

All practitioners, academicians, and researchers recognise the importance of geomechanics (soil and rock mechanics) and geohydrology concepts and theories in engineering geology and geotechnical engineering. Knowledgeable practitioners, however, come to recognise that theories often play subordinate roles on many practical projects and problems. These subordinate roles result from the overriding influence of some or all of: geology, geometry, construction (or constructability); governmental or regulatory agency attitudes and mandates; and the desires, prejudices, schedules, and budgets of clients, owners, and funding organisations.

Notwithstanding, we strongly advocate a thorough understanding of the basic concepts and theories of soil and rock mechanics and geohydrology. We similarly advocate a sound understanding of fundamental engineering

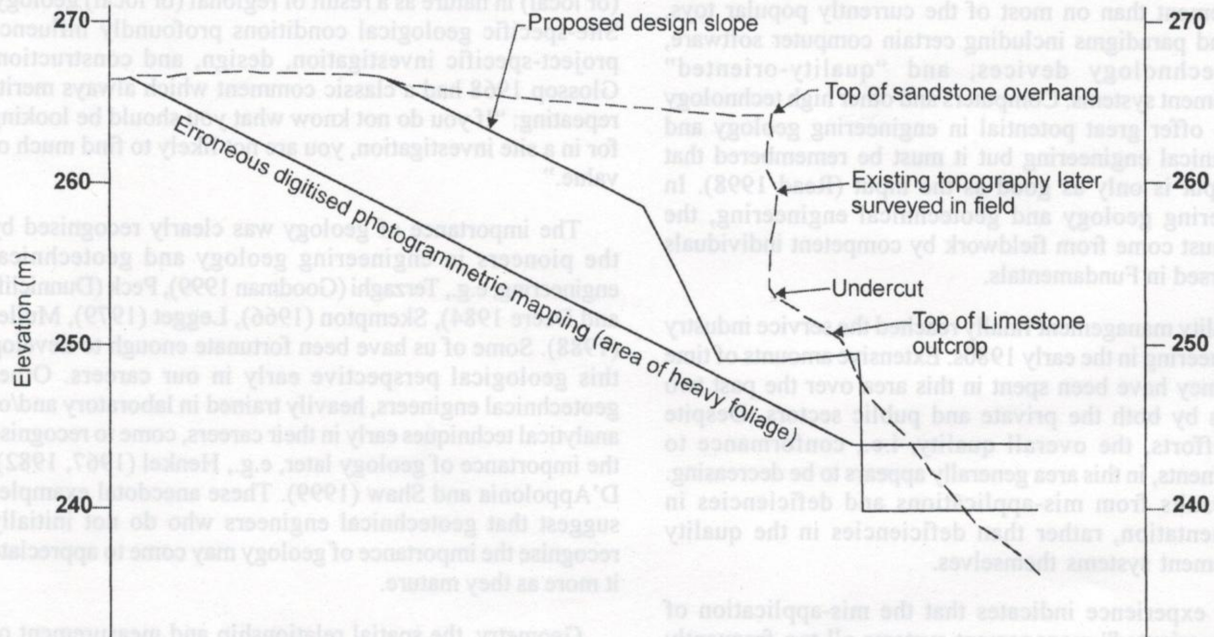

Fig. 1: Erroneous ground profile used for design of highway slope in urban area of United States to meet fast-track schedule

mechanics (statics, dynamics, mechanics of materials, fluid mechanics) as well as hydraulics and hydrology. Concepts and theories from all of these areas often guide decisions even where detailed analyses are not performed.

Observation, imagination, and common sense are personal characteristics vital to success in most endeavours. Their importance in engineering geology and geotechnical engineering should be obvious.

In professional practice in these areas, most of the critical observations are made in the field because that is where key geological features exist and where construction is done. This is well known to most older engineering geologists but not always appreciated by geotechnical engineers despite heroic efforts by Terzaghi (Goodman 1999) and others. Terzaghi (1958) also noted the importance of casual observations, many of which are related to site geology, and the importance of following through in the field during construction. As stated earlier, however, there is now a dangerous trend toward de-emphasising the field element in misguided attempts to reduce costs and expedite schedules.

Observational skills can be learned to a certain extent but they must be exercised to maintain whatever skill level is eventually attained. These processes are enhanced by guidance and mentoring, self-discipline, and exposure to the widest possible array of geology, soil and rock conditions, construction activities, etc. In geotechnical work, observation should include inspection of the site along with all soil and rock samples and exploratory excavations.

Imagination and common sense are necessary to interpret observations in the context of geology, geometry, geomechanics, precedents, and construction or constructability. In this regard, Albert Einstein noted "Imagination is more important than knowledge." This may be somewhat more applicable to research than practice, but it emphasises the importance of imagination in evaluation of geological and geotechnical features.

Unfortunately, imagination and common sense cannot be taught and are seldom hereditary. These attributes can at best be stimulated.

The importance of precedents and experience in engineering geology and geotechnical engineering is well recognised. Peck (1962) noted that one must obtain varied experience on significant work under competent supervision so that, e.g., twenty years of experience does not equate to one year of experience twenty times over. The right mixture of imagination, common sense, and experience produces geotechnical judgement, another subject on which Peck has written extensively (Dunnicliff and Deere 1984).

The end product of most work in engineering geology and geotechnical engineering is construction (or rehabilitation) of some project, structure, or facility. Construction or constructability is fundamental here and intimately related to geology and geometry, i.e., the geotechnical framework of the site. Basic geotechnical design concepts e.g., embankment toe keys, rounding the top of an excavated slope, must be understood by all members of the design team to ensure construction is possible within the available property or right-of-way and consistent with the identified environmental impacts. The development and application of new construction techniques, e.g., directional drilling, microtunnelling, ground stabilisation, environmental remediation, requires all of the above-mentioned Fundamentals of geotechnical engineering practice, i.e., geology through precedents.

Communication is vital to all areas of business and professional practice. Oral, written, and graphical communications are all important in engineering geology and geotechnical engineering. Recent advances in electronic communications and computer technology have greatly increased the amount of information available and the speed by which it is transmitted but, in many cases, the selection of information and the overall *quality* of communication, particularly written and graphical, is actually declining. We now experience "Information Overload," i.e., "technology… drowning the world with information," as we await other technology "to produce new tools to make sense of it all" (*Wall Street Journal* Supplement, June 21, 1999).

Because of the abundance of information available and the ease with which it can now be obtained and transmitted, there is an increasing tendency, at least in the United States, for uncritical presentation of unsorted and unevaluated information of dubious value in geotechnical reports. This often includes vast quantities of output from invalid computer analyses based on the wrong input, model, and/or geotechnical framework.

Until the above-mentioned "other technology" becomes available and is demonstrated to successfully deal with this problem, it is incumbent upon geotechnical professionals to critically sort and evaluate information and data to be presented in reports and other communications. Focus and simplicity are paramount here. The famous KISS principle ("Keep It Simple, Stupid") should be kept firmly in mind with regard to all types of communications.

One other aspect of communication is pertinent to geotechnical activities. The site-specific and project-specific nature of these activities requires clear, timely, and continuing communication between field and office to deal with critical, and in some cases unanticipated, subsurface conditions encountered during both investigation and construction. Lack of such communication has contributed to many failures (Osterberg 1989). The current trend in the United States of using a construction monitoring firm that was not part of the design team often amplifies construction-related communication problems.

Diplomacy, like communication, is vital to all areas of business and professional practice. Diplomacy is particularly important in geotechnical work where considerable numbers of strong-willed individuals render opinions and make decisions, not infrequently on the basis of misinterpreted and/or poorly understood geology and geometry, ill-applied geomechanics, inappropriate precedents, and overly optimistic construction assessments. In addition to technical people, this category also includes some administrators, politicians, and developers.

Certain administrators, particularly those of the "bean counter" (i.e., accountant) mentality, think geotechnical work with natural materials is similar to structural or mechanical work with man-made materials and should be similarly compensated on a lump sum or cost plus fixed fee basis, rather than a more flexible basis consistent with conditions encountered. Administrators, along with politicians, everywhere set arbitrary project schedules without regard to the realities of the work. In dealing with people of all these types, diplomacy (along with persistence) is often crucial to accomplishing anything worthwhile at all!

FIVE MORE FUNDAMENTALS OF GEOTECHNICAL ENGINEERING PRACTICE

Experience over the seventeen years since compilation of the original ten Fundamentals in the previous section of this paper, including review of numerous practice area deficiencies repeatedly encountered (Table 1), suggests five additional Fundamentals:

- History
- Field Emphasis
- Checking
- Redundancy
- Flexibility

These are all related to the original ten Fundamentals of the previous section.

The fundamental aspect of history in geotechnical engineering is perhaps best summarised by Santayana's classic quotation "Those who cannot remember the past are condemned to repeat it." With regard to geotechnical practice, history is a broad area with many important facets -geological, technological, land-use (including project-specific), and cultural.

Geological history is of course part of geology, the first of the original Fundamentals. Longer-term geological history relates primarily to bedrock features while shorter-term geological history, i.e., Pleistocene to Holocene, relates more to surface features and soils. Evaluation of natural hazards, e.g., volcanos, earthquakes, landslides, floods, involves the whole range of geological history up to very recent. This same wide range of geological history can be important relative to the stress history of rocks and soils, especially those which are fine grained and saturated.

Technological history relates to engineering and construction procedures, processes, accomplishments, and failures. Study in this area leads to an understanding of what works and what does not work in certain locations and settings (geotechnical frameworks) under certain circumstances. All of this is related to the original Fundamentals of geology, geometry, geomechanics, precedents or experience, and construction or constructability. A great deal of technological history can be learned by studying classic books, papers, case histories, and projects in geology, geotechnical engineering, and related areas (e.g., construction, civil and mining engineering). The reference list of this paper provides a starting point. Technological history can also be learned by talking with "old timers" experienced in relevant areas. Such study and discussion may stimulate imagination and common sense.

Land use history is relevant to all work in previously developed areas where, as noted earlier, a significant amount of the future infrastructure and other activity is anticipated in both developed and developing countries. Previous mining, construction, manufacturing, and waste disposal activities are all important components of the geotechnical frameworks of sites in such areas (Hamel, 1997). Land use history is related to most of the original ten Fundamentals.

Project-specific history, a sub-area of land use history, is always important in assessment of geological hazards (e.g., slope failures; Hamel, et al., 1998a,b) and in remediation work (e.g., for old dams; Hamel, 1992). This importance was well-stated by Kayyal and Hasen (1998) in connection with flood-control levees:

> Historical behaviour is crucial in developing an engineering model that accurately predicts future behaviour of levees constructed over soft soils. Facility owners would be well served to fully document each construction event as part of their facility management procedures in a form readily accessible for review during levee stability analysis.

These concepts of behavioural documentation are related to the original Fundamental communication and they have significant implications for future infrastructure projects. On many past infrastructure and other projects, it would be good simply to have "As-Built" drawings. There is a steady trend away from preparing "As-Built" drawings on projects in the United States. This trend must be reversed so valuable geometric, modification, and behavioural information is not lost for future rehabilitation or reconstruction activities.

Cultural history is closely related to land use history and its sub-area project-specific history. Cultural history always influences the ways by which projects are developed, including investigation, design, and construction. All of this is related to the original Fundamentals and particularly to diplomacy.

A field emphasis is consistent with traditional geological and civil and mining engineering approaches to geotechnical engineering practice. Unfortunately, university programs in both geology and engineering, at least in the United States, are de-emphasising or eliminating courses and training in

Table 1: Practice area deficiencies observed in numerous recent geotechnical projects

Topography and Geometry	1. Plotted topography inconsistent with actual topography 2. Little or no field verification of topographical contours 3. Little or no direction given to survey personnel 4. Incorrect/inaccurate boring and test pit locations and ground elevations - especially where access roads excavated to borings or test pits and where borings and test pits moved from original locations 5. Property and right-of-way lines not plotted, erroneously plotted, otherwise ignored 6. Cultural features inadequately depicted 7. Critical horizontal and vertical dimensions not considered or not depicted
Reconnaissance, Surface Observations, and Interpretations	1. Inadequate time and budget for background review and field reconnaissance 2. Disregard, lack of review, and failure to consider site history - geological, land use, hydrological (flooding), etc. 3. Failure to locate and stereoscopically scrutinise available aerial photographs and inability to recognise and interpret landforms and other features on such photographs 4. Failure to use available mapping of adequate scale during reconnaissance 5. Non-recognition of critical landforms related to geomorphic and anthropogenic processes and features, e.g., landslides, subsidence, grading, mining, waste disposal, surface and subsurface water flow, erosion and deposition 6. Failure to observe, record, and consider performance of existing structures and other facilities at and near site 7. Failure to sketch or plot key features on plan and cross-section drawings during and after reconnaissance 8. Failure to consider nearby conditions and features beyond site and project boundaries 9. Failure to collect and tabulate the complete and available basic soils, geological, and hydrological setting of the site 10. Inadequate identification and delineation of environmental features and concerns which may be impacted
Borings, Test Pits, and Soil and Rock Sampling	1. Lack of a well-conceived strategy for subsurface exploration programme - key items sought, design and construction information desired, etc. 2. Use of originally surveyed locations and elevations after borings and test pits are moved 3. Failure to draw (or sketch) field cross-sections during exploration programmes for stratigraphic and zonal correlations and instrumentation installation 4. Failure to modify exploration programmes to optimise results as information is obtained 5. Lack of continuous soil samples (split barrel or other, as appropriate) in critical zones, e.g., landslides, dam embankments 6. Failure to use triple core barrels with split inner tubes in coring rock of intermediate to poor quality 7. Borings (and sometimes test pits) not deep enough for stratigraphic or zonal coverage and overlap, particularly on slopes 8. Poor to non-existent stratigraphic correlations 9. Failure to observe, log, and depict key features and discontinuities, e.g., shear zones, gouge seams, thin marker beds 10. Little or no use of test pits 11. Undisturbed samples, e.g., Shelby tubes in soil borings, taken where physically possible or convenient to do so, with little or no consideration of geotechnical framework, mechanisms of deformation or failure, etc. 12. Boring and test pit locations and elevations not established or surveyed prior to exploration 13. Least experienced (least expensive) personnel used to log borings and test pits 14. Failure to utilise (or attempt) alternate methods of undisturbed sampling when initial method(s) are unsatisfactory 15. Failure to monitor, control, and/or modify drilling techniques to improve soil/rock recovery 16. Failure to observe and record where groundwater encountered during drilling and in boreholes after drilling intervals (end of one shift, beginning of next shift) and borehole completion 17. Failure to observe and record where drilling water lost and regained 18. Lack of senior level personnel in field to train, monitor, and mentor junior level personnel
Piezometers and Observation Wells	1. Lack of a well-conceived strategy of what groundwater information is desired and how it is to be obtained 2. Failure to consider and correlate water levels observed in boreholes during and after drilling with (a) those observed later in piezometers and (b) surface features related to surface and subsurface water flow, e.g., ponds, streams, springs, seeps, wet areas 3. Installation of piezometers with tips at specified depths or elevations, without regard to (a) conditions encountered in that boring or other borings or (b) nature of problem being investigated 4. Installation of piezometers and observation wells "at the bottom of the hole" regardless of conditions encountered 5. Installation of piezometers, and particularly observation wells, with sensing zones so long there is no idea where and what groundwater conditions are actually being monitored 6. Reliance on 24 hour water level readings in uncased boreholes rather than installation and monitoring of water levels with piezometers 7. Failure to install any type of piezometer where water levels and/or pore water pressures are important

Table 1 (continued)

Piezometers and Observation Wells	8. Little or no use of piezometer types other than standpipe piezometers, even in low permeability soils and rocks 9. Absence of redundancy in piezometer systems, e.g., some standpipe piezometers along with pneumatic piezometers
Field and Laboratory Testing	1. Lack of a well-conceived strategy for field and laboratory testing, including key data to be obtained and their relationship to analyses to be performed as well as design and construction issues 2. Lack of recognition of key soil and rock discontinuities, e.g., landslide failure surfaces, shear zones, and special requirements for their sampling and testing 3. Lack of recognition of classical soil mechanics considerations, e.g., stress history, stress path, strain rate effects, pore pressure generation and dissipation, undrained vs. partially drained or fully drained loading, strength envelope curvature with normal stress, particularly in testing of fine grained soil and rock 4. Failure to accurately determine specific gravities and unit weights of atypical (light or heavy) soil and rock materials, e.g., metalliferous ores, tailings, slags, stack dusts, chemical wastes 5. Failure of knowledgeable senior personnel to observe and direct (a) extrusion of undisturbed tube samples of soils and (b) selection and preparation of these and other undisturbed soil and rock samples for laboratory testing 6. Failure to (a) review, (b) check, and (c) include in reports detailed data from laboratory and field testing 7. Use of test results without critical technical evaluation of data and results by experienced professionals 8. Failure to install instrumentation, e.g., piezometers, inclinometers, survey reference points, to obtain design data, baseline data, and monitor construction, etc. in critical situations 9. Failure to read, reduce, interpret, and transmit instrumentation data in a timely manner appropriate to the situation 10. Failure to modify originally outlined or specified testing programmes to reflect information obtained during exploration and/or as information is obtained during testing
Calculations, Analyses, and Cost Estimates	1. Geotechnical framework of site inadequately or improperly developed and characterised 2. Lack of checking - concepts, interpretations, computations, reasonableness of results 3. Lack of redundancy - checking by (a) independent methods and (b) other checkers 4. Preliminary cost estimates for subsurface work prepared without subsurface information and not subsequently revised after subsurface information obtained 5. Failure to consider (a) stress history and (b) pore pressures generated by undrained loading of saturated fine grained soils and rocks 6. Failure to consider reasonably expectable ground deformations associated with construction or other activities 7. Oversimplification of geotechnical framework to accommodate available (or familiar) analysis techniques 8. Use of analysis techniques inappropriate to the geotechnical framework, e.g., circular arc slope stability analyses where block or wedge failure modes are probable 9. Failure to explain or justify material properties and other parameters used in analyses, usually because the designer has not thought these through 10. Failure to (a) differentiate between and (b) properly use total and effective stress shear strength parameters and stability analyses 11. Failure to consider stability under both short-term (undrained) and long-term (drained) conditions with saturated fine grained soils and rocks 12. Failure to (a) consider and (b) evaluate alternate designs 13. Failure to communicate and/or coordinate results of analyses, cost estimates etc., with other members of design team 14. Failure to ensure design recommendations incorporated into final plans, specifications, and estimates
Construction Aspects	1. Failure to consider impacts of construction on geotechnical framework, e.g., changes in surface and subsurface water flow, both on the site and outside the site 2. Failure to consider impacts of geotechnical framework and/or geomorphic processes on facilities during and after construction, e.g., flood effects including inundation, scour, uplift, etc. 3. Failure to include in project specifications special provisions appropriate to the geotechnical framework 4. Failure to monitor construction activities (visually and with instrumentation) to confirm design assumptions or modify design accordingly 5. Poor or non-existent construction inspection 6. Construction monitoring and inspection by inexperienced and inadequately trained (i.e., inexpensive) personnel without appropriate guidance and coordination by senior level personnel - compounded by use of monitoring/inspection organisation not involved in design

areas such as surveying, mapping, and other field procedures (Hatheway 1998b). The results of this alarming trend are readily apparent in contemporary practice where the writers have observed a significantly decreased emphasis on field investigations. As Terzaghi (1961) noted, field procedures are principal requirements for providing services in engineering geology. Field procedures are, of course, related to many of the ten Fundamentals listed in the previous section of this paper, most notably geology and geometry.

The first writer has long maintained that most geotechnical problems, along with their solutions, are to be found in the field. Hence, greater emphasis should be placed on field time and fieldwork, particularly by senior (presumably experienced) personnel. Use of experienced personnel in the field increases the probabilities of both problems and solutions being recognised in timely manners. This will generally more than justify the cost of experienced field personnel. Fieldwork by experienced senior personnel also provides opportunities for training and mentoring junior personnel. Engineering geologists and geotechnical engineers must communicate the benefits of fieldwork to all members of the design team and, as appropriate, to those funding project activities (Lemley 1999). All too often, engineering geologists and geotechnical engineers fail to emphasise the importance of their fieldwork and accept inadequate schedules and budgets for these activities.

Checking of work, in both the field and the office (or laboratory) is fundamental to all areas of science and engineering, including geology and geotechnical engineering. Real checking involves thinking through and evaluating concepts and interpretations in addition to numerical checking of computations, critical scrutiny of drawings, and proofreading of written documents. Unfortunately, in the United States, it is not uncommon now for agencies to receive numerous sheets of unchecked calculations and other documents.

Wherever possible, analyses and computations should be checked by independent techniques, even where the latter procedures involve simplified methods, to ensure that the results are realistic. This has been recommended by Osterberg 1989 relative to redundancy in analysis and design.

Independent peer review and independent Boards of Consultants also have roles with regard to checking. The foremost suggestion of Gould 1980 for increasing efficiency in the civil engineering field was simply "do the job right in the first place." He further suggested peer review by an independent consultant or designer analogous to the *Prüfingenieur* of Germany. Gould noted that independent peer review may stimulate the original designer to greater care and diligence. Independent Boards of Consultants, which will presumably include engineering geologists and geotechnical engineers (Hoek and Palmieri 1998), provide valuable services in guidance as well as checking on major projects.

Checking is related to redundancy, another new Fundamental discussed below. Checking is also related to common sense and most of the other original Fundamentals presented in the previous section.

Unfortunately, we have observed in the United States in recent years a general decline in both the amount and the reliability of checking relative to many geotechnical work products. This may result from over-reliance on computers, i.e., "we have software for that," or it may simply reflect declining professional standards and scrutiny. "Quality-oriented" management systems and other paradigms of the modern business world have certainly not reduced the need for old-fashioned engineering-type checking by competent professionals experienced in the work areas being checked. Moreover, these people must have (or take) the time necessary for proper checking. It should be noted that, where properly implemented, "quality-oriented" management systems actually provide structure and encouragement for checking activities.

Redundancy, like checking, is one of those old-time engineering concepts that often finds little favour in the modern world. Unfortunately, in the modern world, redundant activities are not considered to be "value added" and are frequently "re-engineered" out of the design process.

The case for redundancy in geotechnical engineering was well-presented by Osterberg 1989. He called attention to the need for redundancy in reconnaissance and subsurface investigations, laboratory testing, analysis, design, and construction - areas related to many of the ten original Fundamentals of geotechnical engineering practice. To Osterberg's list, we would also add the need for redundancy in field instrumentation and performance observation (Dunnicliff 1988) and risk assessments and risk reduction measures (Hamel et al. 1998a).

Older carpenters in the United States say "Measure twice; cut once." This concept is even more profound for engineering geologists and geotechnical engineers who generally find that remedial work on geotechnical failures, both during and after construction, is significantly more costly than spending extra effort on field reconnaissance or exploration, consulting an alternate reference or source, and/or applying an alternate method of analysis during design.

Flexibility, the last new Fundamental of geotechnical practice, is necessary for operating within the context of the original ten Fundamentals as well as the four new ones listed above. The world, and our practices within it, are continually changing, so we must be flexible and adaptive to survive economically and to continue with geotechnical work (Hamel 1993).

Lifelong learning, creative thinking, quality, professionalism, and ethics should not be sacrificed, however, in pursuit of flexibility and survival. If we lose these attributes, we lose our profession.

SUGGESTIONS FOR PRACTICE IN THE NEW MILLENNIUM

Having reviewed the ten original Fundamentals of geotechnical engineering practice and added five more, we now focus these fifteen Fundamentals on the practice of engineering geology and geotechnical engineering in the New Millennium.

Application of these fundamentals has two basic objectives in terms of engineering geology (Adams 1986):

- Determination of the effects of existing natural features and processes on proposed construction and other activities
- Determination of the effects of proposed construction and other activities on geological conditions and future geomorphic processes in the area

The essence of engineering geology is development of the geotechnical framework of a site or problem. This framework consists of the key elements of geology, geometry, and history relevant to the life cycle of a project, structure, or facility, i.e., investigation, design, construction, operation, maintenance, and abandonment or rehabilitation. replacement (Hamel 1997).

As suggested above, the geotechnical framework cannot be developed in isolation from project requirements. It must be developed with a clear understanding of the proposed construction, both initially and as it may reasonably be expected to evolve throughout the design process. During this evolution of the design, the ability of the engineering geologist and geotechnical engineer to stay focused and informed regarding the proposed construction depends heavily on continuing interdisciplinary communication with other members of the design team.

We have found an observational engineering geology approach to be the most efficient, economical, and reliable one for developing the geotechnical frameworks of a wide variety of sites and problems in diverse geological settings in the United States and elsewhere. This approach is field-oriented with heavy emphasis on field reconnaissance and interpretation of observations within the contexts of (1) basic processes of physical geology relevant to the area and (2) anticipated construction, construction procedures, and land use changes.

Before going to the field, available background information on the region and the site and on the project or problem of concern should be reviewed and assimilated. This is second nature for experienced and competent engineering geologists and geotechnical engineers but not always easy for less experienced personnel. The latter will find check lists and procedural forms, e.g., the SGH Form (Adams and Ruppen 1996), useful in this regard. Such check lists and forms ensure structure and uniformity in developing portions of the geotechnical framework. These check lists and forms should be modified as necessary for regional and local conditions to ensure that they provide an adequate format for compiling basic data.

Check lists and forms, along with guidelines and manuals for investigation and design, are also useful to more experienced personnel, particularly where large numbers of projects are being handled simultaneously and/or projects are "fast-tracked." Check lists, forms, guidelines, and manuals all relate to the Fundamentals of checking and redundancy. Care must be taken, however, to ensure that such aids do not become rigid standards displacing experience and judgement in geotechnical practice (D'Appolonia and Shaw 1999).

Fieldwork includes reconnaissance and mapping of the types applied by many engineering geologists. In this regard, sketches are still useful and highly recommended for recording observations and derivative interpretations (Hatheway 1998a). The old-fashioned art of sketching forces the observer/recorder to think through the geological and geometric relationships of features, at least to the extent they can be sketched on paper.

Most geotechnical investigations, particularly those producing information for design and construction, involve borings and, in many cases, exploratory excavations. Experienced engineering geologists or geotechnical engineers should plan, direct, inspect, and log borings and exploratory excavations to the extent practicable. Where experienced personnel cannot perform all this work personally, they should, as a minimum, plan all exploration programs and inspect all soil samples and rock cores from borings and sufficient soil and rock exposures both natural and excavated, to (1) ensure uniformity and consistency in soil and rock logs and descriptions and (2) have reasonable certainty that critical soil and rock details and discontinuities are not overlooked.

Relevant information from the above-mentioned background review and fieldwork should be summarised on geotechnical plan and cross-section drawings. The emphasis in these drawings should be on substance and clarity relevant to the geotechnical framework of the site or problem, not fancy graphics or CAD wizardry. Production of high-quality geotechnical plan and cross-section drawings has been treated elsewhere (Hamel 1997, 1998a) but, like other basics, requires continual emphasis.

The importance of geotechnical cross-sections (Hamel 1998a) requires particular emphasis here. Geotechnical cross-sections are among the most useful and powerful tools available for developing and portraying the geotechnical framework of a site and for portraying and analysing a geotechnical problem. After thirty years in geotechnical work, the first writer still finds that the contemplative and quasi-artistic activity of drawing geotechnical cross-sections aids immeasurably in interpretation of complex subsurface conditions and analysis of complicated geotechnical problems. Even in the present computer era, we have yet to find a technique of combined interpretation, analysis, and information portrayal which will equal or exceed the value on most geotechnical problems of a well-developed, large, hand-drawn cross-section.

Most, if not all, of the above-mentioned Fundamentals and procedures must be brought together and applied within a sound project development process and quality management system (e.g., Total Quality Management) if future projects are to be successful. The involvement of numerous individuals, disciplines, agencies, funding sources, etc. in most modern projects requires that investigation, design, and construction occur in an organised manner (Lemley 1999). Failures of "quality-oriented" management systems in this regard do not result from flaws in the systems themselves but rather from failures to commit and/or adhere to the management process.

The engineering geologist and geotechnical engineer cannot and should not work in isolation. No matter how dedicated they may be in their own work, including the Fundamentals set forth above, they will not be successful overall without the management support structures that recognise their value and allow or encourage this value to be added.

Using the Fundamentals of communication and diplomacy, the engineering geologist, and geotechnical engineer must be persistent in dealing with other members of the design team to ensure adequate project (and task) funding so that all of the Fundamentals can be applied appropriately to proceed with design and construction in an organised and cost-effective manner.

CONCLUSIONS

Our message regarding geotechnical practice, and particularly engineering geology practice, for the twenty-first century in both developed and developing countries is a simple one: Stick with the basics–the fifteen Fundamentals outlined herein and traditional concepts and procedures related to project development and development of the geotechnical framework of a site or problem. These Fundamentals, concepts, and procedures can be relied upon to meet the challenges and opportunities of the New Millennium.

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