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Prepared by

Civil Engineering Steering Committee:

Simaan AbouRizk	University of Alberta
Barry Adams	University of Toronto
Jack Clark	C-CORE, Memorial University
Ralph Haas (Chair)	University of Waterloo
Peter Kaiser	Laurentian University
Gerhard Kennepohl	University of Waterloo
Gerard Lachapelle	University of Calgary
Don Mavinic	University of British Columbia
Jim Montgomery	Cohos Evamy Partners
Ken Neale	Université de Sherbrooke
Daniel W. Smith	University of Alberta
Peter Steffler	University of Alberta
Hans Vaziri	Dalhousie University
Richard Vincent	Canam/Manac Group

CIVIL ENGINEERING: VITAL TO OUR QUALITY OF LIFE, TODAY AND TOMORROW

Civil engineering plays a vital role between people and their quality of life, the environment and the physical infrastructure of our complex and diverse societies. As natural resources and the productive land base decline, both the challenge and the opportunity for civil engineers is to provide sustainable designs and works which retain and enhance these contacts while protecting biodiversity.

New Challenges. Civil Engineering is in the most challenging time of its history. The need for more innovative and creative solutions is unprecedented. Four basic reasons or axioms drive this need: (1) world population continues to expand (another three billion people expected by 2050); (2) globally, people continue to strive for a higher quality of life; (3) the biodiversity of earth is being reduced faster than at any time in history since the mass extinction some 60 million years ago and (4) there is most recently a new reality of securing the vulnerability and safety of all our infrastructure. What this means for civil engineering is that every activity requires attention, including the incorporation of public pressure for secure and sustainable infrastructure into planning, design, methods of analysis, the use of materials, construction technologies, energy usage, operation and management, risk assessment and environmental protection.

Moreover, there has to be a response to growing public concern over deteriorating infrastructure and recognition of its importance to our economic and social well-being. This needs to be accomplished within reasonable cost and over sufficiently long life cycles.

Vision Statement. Whether Canadians will enjoy a high quality of life will be influenced largely by being pre-eminent in our research, our ability to meet major socio-economic and technical challenges and by education of a new generation of superb engineers. This in turn is predicated on a substantial infusion of research funding to create and pioneer the innovative technology required for:

- Infrastructure, which meets the criteria of protecting biodiversity, vulnerability and security of human life, energy efficiency, comprehensive and long range life-cycle analysis and cost effectiveness.
- Smart systems and infrastructure in transportation, structures, underground services, mining complexes, water and wastewater treatment, and construction sites which involve innovative uses of wireless technologies, advanced materials, continuous remote sensing, broadband communication, dynamic control strategies and spatial technologies.
- Decision support systems based on: (a) the comprehensive use of information technologies, distributed computing and sophisticated algorithms to acquire and handle large databases, and (b) modern business and management practices.

There is a strong foundation for realizing the vision. It includes an extensive record of past accomplishments, a substantive resource base of existing and emerging technical strengths, rapid expansion into new and emerging areas of technology both internally created and selected from other disciplines, and the exploitation of technologies which provide significant added value when adapted to civil engineering.

The record of past accomplishments is well represented by the track record of: (a) some 500 researchers in NSERC’s GSC 06 (Civil Engineering) and (b) practitioners in the public and private sectors who design and build major works worldwide in all areas of civil engineering. For example, Canadian researchers and practitioners are largely responsible for the solutions that enable safe, potable water by counteracting various microorganisms and pathogens. These solutions involve membrane processes, unique filtration technologies, and disinfections through genetic rather than potentially toxic means. As other prominent examples, Canadian researchers and practitioners have gained worldwide recognition through the National Centers of Excellence program, e.g. "ISIS" (Intelligent Sensing of Innovative Structures),"GEOIDE" (Geomatics for Informed Decisions) and the Canadian Water Network. In the roads and airfields area, independent international reviewers assessed the technical capabilities as "world class", quoted from their reviews, in the recent Canada Foundation for Innovation and Ontario Innovation Trust awards in the amount of $4.8 million.

To complement the research technical strengths at our universities, there is extensive technical depth and experience in the private and public sectors. For example, prominent consulting engineering and construction firms such as SNC Lavalin, Stantec, PCL, Ellis Don, Delcan and others apply their expertise worldwide in projects that cover the entire range of civil engineering endeavors from dams to domes to skyscrapers to highways, mass transit and infrastructure engineering and management.

The dynamic and creative nature of civil engineering is well illustrated by its expansion into new areas and its exploitation of new and emerging technologies. Information technology, for example, is as much the purview and tool of civil engineering as any other discipline in such applications as intelligent transportation systems, remote sensing and image analysis for hydrologic models, spatial data in the vast set of GIS (geographic information systems) applications, robotics in construction, and neural networks and genetic algorithms in assessing high risk safety hazards. Civil engineering is a dynamic, creative, adaptable, forward moving discipline, which is and will continue to be positioned to both develop new technologies and adapt them from such other areas as biotechnology, microelectronics, medical sciences, business and economics, and e-based communications and commerce.

STRATEGY FOR FUTURE DEVELOPMENT

The massive gains in economic development and social advancement of the past century have been due in large part to provision of the physical and management infrastructure of cities and resource industries. This infrastructure has both made possible and benefited from advanced technologies. It has also made possible unprecedented wealth creation, quality of life and public safety. However, advancement of the human condition in the next century is challenged by the previously noted rapidly increasing global populations combined with increasing expectations of quality of life and an increasingly stressed and fragile environment. To meet this challenge and realize the vision will require a new generation of Civil Engineering innovation and technologies. The breadth of Civil Engineering and its enormous social impact afford numerous possibilities for such innovation. The selected strategic elements are briefly discussed as follows:

Infrastructure for Sustainable Development. It is arguable that no other profession has as great an impact on human welfare and the environment as Civil Engineering. This makes paramount the need for sustainable approaches in all of Civil Engineering practice. Preventive approaches will require the development and widespread application of new forms of life-cycle analysis into the foreseeable future to establish sustainable alternatives in the planning, design, construction, operation and management of all Civil Engineering infrastructure – alternatives that meet stringent criteria of energy efficiency, utilization of renewable reserves and recycled materials, and minimization of residuals. Mitigation approaches will require the development of innovative and cost-effective physical, chemical and biotechnologies for water and wastewater treatment, air pollution control, solid and hazardous waste management, environmental remediation, habitat restoration and control of the indoor environment. Some examples of such technologies are membrane processes, ultra and nano-filtration, disinfections by genetic disruption, technologies for treatment of endocrine disrupting compounds, and the anaerobic treatment of wastes and the remediation of contaminated soils by genetically engineered microbes.

Smart Systems and Infrastructure. As national and global populations increase, become increasingly urbanized and strive for affluence, the challenge of providing efficient, sustainable urban transportation becomes staggering. The infrastructure expansions of recent decades are not the answer. High degrees of efficient and secure vehicle, passenger and information movement must be developed and implemented. The vast array of available and emerging information technologies present real and exciting opportunities to continuously monitor these networks, detect incidents, calculate dynamic control strategies for system operation, and actively exercise control on the network in real time.

The foregoing developments have equally exciting parallels in the operation of mining complexes, water supply and wastewater treatment systems, construction sites, flood control systems and buildings, and various energy efficient systems to name a few. Other advanced technologies such as robotics offer new possibilities from construction engineering operation to personal vehicle operations to waste management.

Our physical infrastructure – buildings (commercial, industrial, public and residential – from low to high rise), bridges, offshore structures, tunnels, pavements, various types of pipelines, cables, and the like – requires massive financial investments to provide *essential services*. New infrastructure as well as the rehabilitation of existing infrastructure will have innovative applications of new sensing technologies and advanced materials. Continuous sensing of strain, deflection, temperature, chemical condition, etc. of buildings and bridges will allow timely intervention on their operation, repair and rehabilitation, as well as advancing the state-of-the-art of predictive modeling in future infrastructure design. “Smart pipes” will have the capability of sensing their structural condition, operating pressures under transient conditions, chemical and biological characteristics, and flow rates along with communication channels at the manufacturing stage. Advanced materials such as the next generation of fiber-reinforced carbon and polymer composites, optical fiber sensing composites, shape memory alloys, and high performance cements and concretes will offer new design opportunities.

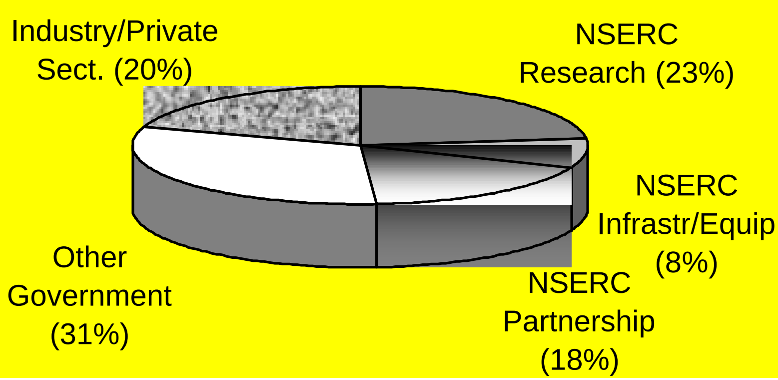
Decision Support Systems. Past Civil Engineering practices have relied heavily on the specification of system inputs based on codes, standards, warrants and empirical rules. The ability to capture and manage vast data bases; to develop and apply statistical, simulation and optimization algorithms; to deploy artificial intelligence; and to display and communicate multi-objective information to decision makers offers new opportunities to base future practices on system performance rather than system input in an integrated, life-cycle context through decision support systems. In addition to meeting the paramount objectives of efficiency and safety, the new paradigms of environmental sustainability, multi-stakeholder, public participation, public-private partnerships and modern business practices require this seamless form of data management and decision support.

SPECIFIC PRACTICAL PROPOSALS

Realization of the proposed Civil Engineering vision is based on ambitious expectations. It will require additional investments in people, knowledge, and innovation. While NSERC research grants are providing valuable base funding for ongoing research and support of graduate students, we are now proposing strategically selected investments for advantageously positioning Canadian Civil Engineering to meet the new challenges and expectations. The areas targeted are: A) Funding for strategic research initiatives, B) Support for advanced training of highly qualified graduates and C) Support for an increased number of applicants.

The traditional sources and composition of research investments in Civil Engineering, which were compiled from a survey by the Steering Committee of Civil Engineering Departments, are depicted in Figure 1. Shown are the percentages of funding from various government and industry sources, for a total estimated annual expenditure of $42.0 million.

Figure 1. Composition of Grants and Contracts



Civil Engineering has a wide base of funding support and because much of the discipline's activities are directed to public needs, the major portion of the research (80%) is supported from public funds. Compared to other disciplines, there is certainly less dependence on private sector support. But while Civil Engineering achieves maximum cost-effectiveness from public funds, there is also a need for substantially increased funding overall to meet future needs. To this end, we are submitting in the following sections, specific, practical research proposals for funding within the targeted investment areas. These proposals, which are all considered of equally high priority, ask for an increase over 4 years of \$3.4 million over and above GSC06's base budget of \$12.7 annually (2002-03) minus \$1.27 million (10% contribution to the reallocation pool) = \$11.43 million, divided by 4 (e.g., because a 4-year cycle is involved, only about 1/4 or \$2.9 million is available annually for renewals and new applicants). Thus, the new requested annual amount of \$2.9 million plus \$3.4/4 = \$3.75 million represents about a 29% increase (10% of this is recovery of the reallocation contribution for a net of 19%). Implementation of the proposals would be through the annual grant competition (GSC06) to ensure excellence and selectivity.

A) Funding for Advanced Research Initiatives in Civil Engineering

To advance and accelerate our research activities means not only being able to attract the brightest and best, but it also means considerably higher costs. The workload for professionals, graduate students and support staff will increase substantially and will be more diversified and demanding. Relevant knowledge and expertise, both internally developed and adapted from other disciplines, are essential components.

In addition to emphasis on generating new ideas and innovative technology, there will be a multidisciplinary approach to importing emerging technologies from other disciplines. For example, in monitoring roads and airfields, the required ancillary expertise from other disciplines will include high speed vehicle mounted imaging systems using CCD camera technology, laser range finding, precise positioning and real time data processing technology.

Proposal 1: Infrastructure for Sustainable Development - \$ 0.125 million annually

This increased funding will be applied toward research and development of sustainable alternatives in the planning, design, construction, operation and management of all Civil Engineering infrastructures. The resulting technologies must meet stringent criteria of energy efficiency, and utilization of renewable resources and recycled materials. In addition, research will be carried out for such mitigation technologies as innovative and cost effective physical, chemical and biological water treatments, air pollution control, as well as solid and hazardous waste management. The Walkerton fiasco puts the need and potential costs into perspective.

We propose that the GSC-06 select each year grant applications which are leading innovative research initiatives in sustainable development and award an additional \$25 K to the top 5 researchers. Such support will assist in covering the increasing cost of research, including field surveys, environmental monitoring and analytical testing, which are needed but not necessarily part of traditional civil engineering research facilities. Other costs involve development and construction of prototype processing equipment (e.g. water treatment) and full-scale testing and demonstrations. The funds will not only facilitate and exploit the interdisciplinary approach, but also allow for an acceleration of technology advances and cost-effective commercialization.

Proposal 2: Smart Systems and Infrastructure - \$ 0.125 million annually

This funding will be applied toward research in designing smart systems for all types of civil engineering infrastructure. Available and emerging technologies, such as information technology, global positioning systems, broadband digital communication using fiber optics, and robotics will be evaluated for sensing and monitoring the performance, efficiency, safe use in such applications as transportation, mining, off-shore structures, pipelines, tunnels, cables, and security. In addition, the development and application of "smart materials" will be pursued. Examples include structural components that are self-repairing and capable of altering their shape, orientation or stiffness in response to changing operation and environmental conditions, such as occupancy, climate, wind, ice and earthquake loads.

We recommend an additional, yearly grant of $ 25 K to the 5 most innovative and promising research submissions. The costs are high for evaluation and selection of new materials such as advanced composites for reinforcing structures, pilot testing, developing new design methodologies, and full-scale trials. Additional costs need to be assumed for modifying new products and novel emerging technologies for civil engineering application, which may involve a crossover into other disciplines and acquisition of additional expertise. For some projects funds will also be required to do long term performance studies and environmental and economic impact assessments for market development.

Proposal 3: Decision Support Systems - $ 0.10 million annually

The funding for this research proposal will be used to develop support systems that will enable decision makers to base future designs on systems performance. Shared, integrated data bases and distributed computing platforms will be created, which offer dramatically new possibilities for increasing the productivity and effectiveness of infrastructure; this will include delivery from project conception, planning, financing, specification, construction, commissioning, operation, and management, through to decommissioning.

An additional yearly funding of $ 20 K is recommended for the 5 best submissions that meet the requirements outlined in this proposal. Expenses covered by this fund include the development of automated and computerized, high- speed data collection systems, field data collection, as well as construction of comprehensive and integrated databases and development of decision models.

B) Support for Training of Highly Qualified Graduates

Considerably higher demands for highly qualified engineers have resulted from an aging cohort, economic growth and a shift in responsibilities and custodianship for civil engineering infrastructure from senior governments to municipalities and the private sector. Not just the numbers, but also the scope and diversity of qualification are involved. Thus, there is a real need to significantly increase the pool and secure the future supply by training a greater number of highly qualified graduates. NSERC's existing scholarship program contributes substantially to this goal, but the reality is that there are additional, highly qualified students who will need to be supported from faculty research grants, in order to meet the demand.

Proposal 4: Increase the Number of Graduates Students - $ 0.4 million annually

This substantial increase in funding will be used to expand the number of graduate students in Civil Engineering, support an enhanced training program and provide adequate remuneration for a major share of the increased research workload, which will be carried out by the graduate students. In the graduate studies program, which produced 780 master's degrees and 478 Ph.D.'s in 1999, we anticipate an annual increase to 860 and 520 graduates respectively in the next four years..

Researchers who pay their graduate students from their NSERC research grants, typically incur costs of over $ 30 K per student (base support plus associated cost). In order to enhance the training of graduates and at the same time stimulate innovative research, we propose that 20 key researchers, whose research program best reflects the Canadian Civil Engineering vision for the future direction, would receive additional funding, $20 K each, for graduate student support.

C) Support for Increased Number of Applicants

An expansion of the number of grant applications in Civil Engineering is expected to achieve the goals and accomplish the tasks set out in the proposed research program. In particular, there will be a substantial increase in new applicants, as retired faculty is replaced.

Proposal 5: Additional New Applicants - $ 0.1 million annually

This amount will be used to selectively "top up" by $ 20 K each, 5 of the most promising new applicants (from an average of about 50 new applicants per year) in Civil Engineering's vision. This investment is intended to address the demand for higher research capability and excellence as well as the anticipated supply for a growing number of experts needed in the immediate future.

Summary. These five proposals outlined above, total only $ 0.85 million per year over the next four years. By comparison, in a comprehensive virtual funding exercise, which was conducted by GSC-06 in the context of the1998 research grant competition, the committee concluded that for no budgetary constraint a funding level 2.5 times that of the actual budget could be justified. The increased funding requested in this submission is entirely justifiable, particularly in view of the urgent needs and the potential return on research investment.

CONSEQUENCES OF NO REALLOCATION FUNDS

The results of the previous two reallocation exercises have led to GSC06 now exhibiting one of the lowest success rates, and highest degree of selectivity, for grant renewal and new faculty. No reallocation funding in this exercise would most certainly undermine any ability to seed new research initiatives. The novel approaches and envisioned strategies, that are fundamental to meeting the many challenges facing the Civil Engineering community will simply not happen in an acceptable time frame if no new funding is provided.

When considering the consequences, the point must be made that civil engineering infrastructure comprises virtually everything upon which modern society depends. At the same time, we need to realize that this infrastructure is critical not just to the quality of life, but in many instances to the actual safety, health and support of life. Examples of the specific and significant consequences, in terms of major costs, losses and needs include the following:

- The **loss of creativity in research** would be a serious consequence of lack of funding and will most certainly stifle the generation of new technology and innovative solutions. Supporting and rewarding highly qualified personnel on short term, project-oriented and tightly controlled research contracts is not the answer. Incentives will be required to foster and attract excellent researchers. Also, the new generation of civil engineers is expected to be highly flexible and versatile in embracing new ways and technologies, changing venues and multi-disciplinary approaches to research.
- The **need for education and training** is profoundly real and will be severely affected by a further reduction in funding. In many areas of Civil Engineering, there is already a severe shortage of highly qualified personnel. A reduction of funding for training and development of young researchers, just when industry is seeking to hire more highly qualified personnel, will prove to be costly.
- The **cost of delays** for major projects, including such mega-projects as the arctic pipeline, where long-term performance and environmental impact are key elements, can easily grow into many millions of dollars. Not only do the costs of the project increase with time, but also the cost of doing research, which is already particular high because of extensive laboratory and field testing, full-scale instrumentation and site-specific environmental impact studies.
- The **cost of defaults and mistakes,** because available innovative technology was not ready or properly adapted to infrastructure applications, can be astronomical. Earthquake and flooding come to mind, but there are many other examples such as industrial emissions, traffic congestion, or more recently water quality and infrastructure security, where innovative solutions will have a tremendous impact on the cost to society.
- The **loss of competitive edge and eventually jobs for Canadians** will be a direct result of letting curiosity oriented and fundamental research become dormant. The Canadian Civil Engineering community stands to lose its worldwide rank as a pioneer and its international leadership in this area.

While some specific consequences of no funding could be disputed, the stakes in civil engineering research and the development of new technology remain unquestionably very high. Considering the magnitude of potential cost and losses, and the substantive return on research dollar investment for funding, the option of no funding is simply one we cannot afford.

IMPLEMENTATION OF THE LAST EXERCISE

The last reallocation exercise resulted in only $125,060 received by Civil Engineering from the reallocation pool. While $283,725 was subsequently received (from general increases), the almost 10% contribution to the pool not being recovered had an immediate impact on the research challenges emerging at that time and the turnaround in the demand for civil engineering graduates. These challenges include the extension of frontiers in mining, oceans, arctic and space, rapidly deteriorating infrastructure, and environmental requirements for sustainable development. The result is an unprecedented demand for innovative solutions and creative designs that can be met only by a vigorous, dynamic and sustained research program.

While the last reallocation exercise had a negative impact on many research programs, the Civil Engineering community has been able to secure some major research funding in specific areas from other sources. For instance, the construction industry, with a history of reluctance to support research in universities, now provides significant support to a national network of researchers coordinated through an NSERC Chair positioned at the University of Alberta.

However, a major downside of the drop in basic funding is a serious reduction in money to support students. Examples of observed impacts are:

- **Contract research funding:** Soft money carries with it hard timelines. The objectives are set with specific target dates and the work must be carried out to specific schedules, budgets, and deliverables. This provides employment opportunities to professional engineers, but it reduces the ability to support graduate students where scholarly research over a period of several years is required to achieve the graduate level, especially the PhD. When basic research funds are in short supply more graduate students opt for programs that do not require a research component. In turn, this diminishes more fundamental research needed for substantive technological advances.
- **Marginal stipends:** Reduced NSERC funding seriously limited the maximum allowable stipend that could be paid to students. Compensation for even the best candidates is woefully low and graduate students are required to assume an increasingly greater debt to support their academic program. More graduate students are attracted to the US at much higher salaries and lower taxes. Civil Engineering in particular has been hit hard in attracting Canadian graduates because of a lack of ability to provide adequate funding.
- **High-profile disciplines:** Undergraduate students have recently gravitated to the high-profile disciplines such as computer science. As a result, the need and funding for graduate students in Civil Engineering has exceeded the supply.

Today, many major projects and mega projects, such as the northern pipeline, the heavy oil development, and off-shore oil and gas projects are being deferred and/or becoming much more costly, not for lack of market but largely because the human resources necessary for the design work and construction cannot be found. The demand for innovative designs, new construction technologies and improved efficiency has never been greater. Civil engineering research has an important role in responding to this demand. The previous reallocation exercise has demonstrably affected the ability to respond.

In summary, the greatest impact of the reduced funding has been significantly less support for graduate students and a shift from more fundamentally based, longer-term strategic research to specific, industry related research requiring short-term results. If allowed to continue in this fashion, the result does not bode well for either the Civil Engineering community itself or the country as a whole.

REFERENCES AND ACKNOWLEDGEMENTS

The Civil Engineering Steering Committee relied heavily on workshops, consultations throughout the community and with our associated disciplines, and a large variety of documents, statistics, etc. A selected list of key events and references is provided as follows:

- MIT Department of Civil and Environmental Engineering, "A New Millenium Colloquium on the Future of Civil and Environmental Engineering, March 19-21, 2001 (available on MIT web site)
- Vaziri, H., "Discussion on Future Prospects and Emerging Growth Areas in Civil Engineering", prepared for June 7 and 8 Workshop and Meeting in London, Ont., June 6, 2001
- Ralph Haas and Gerhard Kennepohl, "Report on NSERC Reallocation Workshop and Meeting with Canadian Chairs and Heads of Civil Engineering Departments (CHCED's), June 7 and 8, London, Ont.", August 8, 2000 (note, this was posted on the Steering Committee's web site)
- Ralph Haas and Gerhard Kennepohl, "Results of January 28 and 29, 2001 Steering Committee Workshop in Toronto", January, 2001 (note, this included a variety of background documents, and was also posted on the Committee's web site)
- 1. Highly Qualified personnel, NSERC Scholarship and Fellowship Division and Policy and International Relations Division Report, May 2001.
- 2. Research Grants Discipline Dynamics, NSERC Policy and International Relations Division Report, May 2001.
- 3. NSERC Research Program Statistics, Grantees in Civil Engineering, April 2001.

Finally, acknowledgements are due to many individuals and organizations, not the least of which is the excellent cooperation and help from NSERC staff. In addition, deep appreciation is extended to the members of the Steering Committee, including Dr. Gerhard Kennepohl, our "consultant" who contributed an enormous amount of time and effort, and many others in public, private and academic sectors of our community who were enthusiastic volunteers in their commitment and assistance. It has been both a pleasure and an honor to work with so many talented individuals.

Ralph Haas, CM, FRSC,FCAE
Chair, Civil Engineering Steering Committee