Application - Research Tools and Instruments

Identification

Applicant

Family Name: Woods **First Name:** Joshua

Middle Names: Edward

Current Position: Assistant professor

Administering Organization

Organization Queen's University

Department/Division Civil Engineering

Application

Application Title Real-time Digital Image Correlation System for the Evaluation of Critical Infrastructure Assets

Language of the Application (•) English ( ) French

Suggested Evaluation Group 1509 Civil, Industrial and Systems Engineering

Hours per month to be devoted to the research/activity, or use of equipment or facility 40

Summary of Proposal

Summary

Digital image correlation (DIC) is a technique that uses cameras to measure displacement and strain at hundreds of locations over the surface of a structure. Rapid advances over the last decade in DIC technology have resulted in improved accuracy and more efficient algorithms that allow users to visualize results in real-time. These advances provide a unique opportunity for scientists and engineers to exploit DIC in the laboratory and in the field to improve the fundamental understanding of the behaviour of built infrastructure.

The objective of this NSERC RTI proposal is to transform the discovery, innovation, and training capabilities of the infrastructure engineering research group at Queen’s University by supporting the purchase of a real-time DIC system to form an innovative non-contact and mobile structural behaviour and safety evaluation system that can be deployed in the laboratory or in the field and that is urgently needed by their graduate student researchers to develop the next generation of safe, sustainable, and resilient infrastructure.

Buildings: Efforts in Canada to reduce greenhouse gas (GHG) emissions and combat climate change have fueled the demand for sustainable structures. However, these structures are often complex, because they use novel sustainable materials, or they have optimized geometry that makes it impossible to measure and understand their behaviour using traditional discrete sensors. The requested DIC system is urgently needed to enable measurement of crack patterns, displacement fields, and stress concentrations that are critically important in the development of sustainable structures.

Bridges: Canada’s bridge inventory is deteriorating. Coupled with the increasing effects of climate change, there is an urgent need to monitor the condition of existing bridges and culverts in the field to ensure public safety. The requested DIC system will enable real-time assessment of the live load response of bridges and culverts, which can be used to evaluate these critical structures and provide quantitative performance measurements beyond what has traditionally been possible using visual inspection or discrete sensors and ensure Canada’s transportation networks remain functional, resilient, and safe.

Railways: Canada’s railway networks are essential for transportation of goods and services, but these structures are being subjected to heavier loads and climate change is altering the conditions in which they operate. The requested DIC system is urgently needed to monitor rail condition in the field and understand how real-world conditions are affecting performance, to prevent failure and protect public safety.

The requested equipment will offer cutting-edge, hands-on training opportunities for 50 HQP over the next 5 years and will prepare them with advanced expertise that is highly sought-after in industry and academia.

Second Official Language Translation

Proposed Expenditures

	Year 1 Amount
Equipment or facility	
Purchase or rental	$149,996
Subtotal	$149,996
Other (specify)	
	$0
Subtotal	$0
TOTAL PROPOSED EXPENDITURES	$149,996
Total Cash Contribution from Industry (if applicable)	$0
Total Cash Contribution from University (if applicable)	$0
Total Cash Contribution from Other Sources (if applicable)	$0
TOTAL AMOUNT REQUESTED FROM NSERC	$149,996

Activity Details

Certification Requirements

Does the proposed research involve humans as research participants? ○ Yes ◉ No

Does the proposed research involve animals? ○ Yes ◉ No

Does the proposed research involve human pluripotent stem cells? ○ Yes ◉ No

Does the proposed research involve harzardous substances? ○ Yes ◉ No

Impact Assessment

Will any phase of the proposed research take place outdoors? ◉ Yes ○ No

1. RESEARCH PROGRAMS TO BE SUPPORTED BY EQUIPMENT

Climate change in Canada and globally is causing more frequent and severe weather events that are having significant environmental, economic, and social impacts. This has highlighted the importance of reducing greenhouse gas (GHG) emissions to combat the effects of climate change, which has fueled demand for sustainable structures. However, climate change is also impacting existing structures, and is subjecting them to extreme conditions and forces they were not designed for and eroding their supporting systems.

The objective of this NSERC RTI proposal is to transform the discovery, innovation, and training capabilities of the infrastructure engineering research group at Queen's University by supporting the purchase of a digital image correlation (DIC) system. The system would form an **innovative real-time, non-contact, and mobile structural behaviour and safety evaluation system** that would provide the ability to take distributed high-resolution measurements over a range of surface sizes (from 0.01 – 4m^2). It would allow the group to study the behaviour of structural components in the laboratory and full-scale structures in the field. The use of traditional discrete sensors (e.g., strain gauges and displacement transducers) are not feasible to collect this type of distributed data because of the large number of sensors required, lengthy installation time, and high cost of the instrumentation and data acquisition systems. The requested DIC system is a more cost-effective approach to obtain real-time distributed data that is essential to develop the fundamental engineering science, innovative monitoring tools, and train the next generation of engineers to **protect existing infrastructure** from the effects of climate change and **design resilient and sustainable built infrastructure**. The supported research programs focus on three important areas:

Buildings (Drs Fam, Genikomsou, Hoult, MacDougall, and Woods): Building construction is a significant source of GHG emissions, a main contributor to climate change. It is estimated that the materials, including steel and concrete, used for building construction account for between 10 and 15% of global GHG emissions. As Canada and the world seek innovative solutions to reach net zero by 2050, reducing the environmental impact of the construction industry will be a key contributor to this effort. This includes developing new approaches to building with traditional materials (e.g., steel and concrete) that reduce embodied carbon, either through changes in design thinking or the use of new innovative materials. Alternatively, building with sustainable materials like wood has the potential to sequester carbon, and the structural system itself can act as a carbon offset. However, significant questions remain surrounding how to build these sustainable structures so that they are both functional and safe.

The requested research tool would enable accurate capture of complex 3D displacement and strain fields over the surface of a structural element in real-time. Initially, the system will be used to study two promising sustainable structural systems: (1) mass timber, and (2) low carbon concrete. While the demand for tall mass timber structures is rising, significant questions remain surrounding how these structures behave under realistic loading conditions. Because wood is an orthotropic material, complex loading conditions induce complex stress distributions, which are challenging to measure using discrete sensors. Using DIC, there is a unique opportunity to measure full-field strain distributions and understand these complex behavioural mechanisms for a range of structural elements under a variety of load conditions. Research projects supported by the purchase of the requested equipment will be used to understand the behaviour of timber bolted connections under seismic and fatigue loads (1 MASc, 1 PhD), glued-laminated timber beams under freezing and thawing (1UG, 2 MASc), cross-laminated timber (CLT) slabs under moving loads (2 UG, 1 MASc, 1 PhD), and the in-situ performance of mass timber structures in the field under live loading (1 UG, 3 MASc).

A second research program related to buildings that the requested equipment will support is the development of the next generation of sustainable reinforced concrete (RC) infrastructure. Concrete is the most widely manufactured material and Portland cement, the active ingredient in concrete, accounts for up to 8% of global CO_2 emissions. The supported research program aims to reduce the environmental impact of the concrete industry through optimization of the design, analysis, and construction of RC buildings. Through an industry-driven collaboration with engineering consultants, architects, contractors, and material suppliers, the goal is to reduce the Portland cement consumption of RC buildings by 50%. The research will culminate in the construction of a demonstration structure that will showcase innovations and enable field monitoring of optimized RC structures under real world conditions. Cement reduction is achieved by reimagining the form and composition of RC components, through optimization of geometry and the use of novel materials (e.g., low carbon cement and ultra-high performance concrete). The acquisition of the requested DIC system is key to developing an in-depth understanding of the complex behaviour of these components and will enable accurate capture of stress concentrations, interfacial stresses, and crack distributions in the laboratory. Research projects supported by the requested equipment include studying shape optimized RC beams using hybrid simulation (1 UG, 2 MASc), functionally graded concrete slabs (1 UG, 1 MASc, 1 PhD), and monitoring the in-situ performance of the demonstration structure (2 UG, 2 MASc, 1 PhD).

Bridges (Drs Fam, Hoult, Moore, and Woods): The condition of bridge and culvert infrastructure in Canada is deteriorating and placing increasing stress on infrastructure owners and their budgets to maintain these critical assets. The 2019 Infrastructure Report card estimates that over 40% of publicly owned bridges are in poor or very poor condition. Furthermore, bridges in Canada are being subjected to more frequent and severe weather events, which is exacerbating the rate of deterioration and subjecting them to forces for which they were not originally designed. Monitoring in-situ bridge and culvert performance is critical to assessing their behaviour and ensuring these structures remain operational and safe. Furthermore, it is important to develop innovative systems that are resilient and can withstand the effects of climate change.

Two research programs where the requested system will be used are: (1) field monitoring of flexible culverts and (2) assessment of novel bridge materials under moving loads. In the field, the requested equipment will support studies focused on understanding the structural behaviour of bridge infrastructure under live loads through the measurement of displacement profiles along the length of the bridge while also measuring high-resolution strain distributions on the surface of a critical region of the structure (e.g., at a support). Initial work by the research team has demonstrated the value of distributed measurements for field assessment of culverts. However, these studies were limited by the lengthy processing time associated with using in-house analysis tools. The proposed project would involve parallel studies, one focusing on the rapid assessment of road culverts in partnership with the City of Kingston (2 UG, 1 MASc), and the other focusing on the assessment of rail culverts with industry partner CN Rail (2 UG, 1 PhD). In both studies, the real-time measurements enabled by the requested system would be used in conjunction with numerical models of culverts to develop rapid assessment tools for use by the partners.

The requested equipment will also support measurement of displacement and stress distributions in large-scale testing of bridge infrastructure. Through generous CFI investments in laboratory facilities at Queen's, including the Rolling Load Simulator (ROLLS), this has enabled experiments on full-scale bridge structures under moving loads, including RC bridge decks. The second research program combines the ROLLS with the requested system to assess the performance of novel materials for bridge construction under moving loads. Traditional testing of these structures involves placing loads at fixed locations which result in fixed crack patterns in the concrete and maximum strain locations. However, the ROLLS coupled with the requested DIC system will enable researchers to explore how crack patterns and maximum strain locations develop and change. In the first phase of this research, tests will be undertaken with conventionally reinforced bridge decks to understand, for the first time, how cracks patterns and strains develop (1 UG, 1 MASc). In the second phase, novel reinforcing systems that enable rapid construction, such as stay-in-place forms (2 UG, 2 MASc, 1 PhD), and concrete types that reduce carbon content (e.g., functionally graded concrete), and ultra high-performance concrete will be explored to help develop the next-generation of innovative, sustainable, and resilient bridge infrastructure (2 UG, 2 MASc, 1 PhD).

Railways (Drs Hoult, Take, and Woods): There is approximately 50,000 km of rail track in Canada, and a significant percentage of it passes over regions of variable and often degrading stiffness. The infrastructure research group at Queen's has established significant expertise in the use of DIC and proven its value for assessing rail tracks including in areas of poor ground support and transition zones. However, to date the challenge with using DIC for this application has been that the system requires extensive training and time for data processing, limiting both its use and effectiveness. The requested system would overcome these barriers and enable several field sites to be studied by a single student allowing for trends in behaviour to be evaluated and general approaches to assessment to be formulated.

The proposed research in this area will focus on two important concerns: (1) bridge transitions and (2) rails constructed on permafrost. Previous work on bridge transitions was performed at one site under a limited number of trains. Our proposed work using the requested DIC system would be done in conjunction with partner CN Rail and would involve monitoring several identified bridge transition zones of concern. Using a large database of measurements, the research team will use Gaussian processes to better understand how critical variables (e.g., train speed, bridge length etc.) influence the length and critical displacements developed at transition zones (2 UG, 1 MASc, 1 PhD). Climate change is causing areas of permafrost to thaw resulting in excessive deformation of the infrastructure built on top of this layer, which includes rail tracks. The requested system will be trialed as a rapid deployment assessment tool to measure the performance of these critical sites as soon as rail operators suspect potential problems. This will help prevent derailments and assess rehabilitation strategies (2 UG, 1 MASc, 1 PhD).

Industry Collaboration: In each of the research programs, it is expected that the requested equipment will be key in the establishment and expansion of research partnerships with industry (supported by NSERC Alliance grants). Industry partners include Canadian engineering consulting companies (e.g., Arup, Hatch Ltd., and BGC) who are interested in contributing to the development of sustainable solutions to combat climate change and asset owners (e.g., City of Kingston and CN Rail), who are interested in ensuring that their existing infrastructure can withstand the increased demands resulting from climate change. Dissemination of results at academic conferences and publication in high-quality journals will ensure that the scientific knowledge generated by this research is distributed as widely as possible.

Consideration of EDI in Supported Research Programs: The research team values and implements EDI best principles in all stages of research, from generation of ideas, to hiring of HQP, field and laboratory work, data analysis, and knowledge dissemination. Concrete practices for every research program include: (1) ensuring recruitment materials use inclusive language and are distributed among equity seeking groups on campus and throughout the broader community, (2) EDI training for all team members (applicants and HQP) through Equity Services at Queen's, (3) creating a positive, supportive, and inclusive research culture, including in meetings and the laboratory, (4) ensuring that the ability to do field work as part of the research is equitable and will have provisions for persons with disabilities or different needs. Ultimately, the team recognizes that a diverse research team brings forth new perspectives, opinions, and ideas that lead to more innovative and exceptional scientific results.

2. REQUESTED EQUIPMENT

A VIC-3D Digital Image Correlation system is requested to enhance the discovery, innovation, and training capability of the research team at Queen's University. Critically, this system has real-time capabilities, which enables visualization of live 3D displacement and strain data at sampling rates up to 5Hz. No other system of this kind exists at Queen's, and its acquisition is the most cost-effective approach to measuring distributed strain and displacement data both in the laboratory and in the field.

3. IMPACT OF A DELAY IN THE EQUIPMENT ACQUISITION ON THE RESEARCH

The research described in this proposal would not be possible without the requested equipment. Current image processing algorithms used to conduct DIC by the research team are limited to 2D, do not have real-time capabilities, and involve a steep learning curve to properly use the software and obtain accurate results. Thus, **a delay in obtaining the equipment would significantly impede discovery and innovation** in relation to advancing fundamental scientific understanding of the behaviour of our built environment under the effects of climate change and the development of novel, sustainable, and resilient structures. Furthermore, it would significantly reduce the impact of the research and opportunity for hands-on experience using state-of-the-art equipment for HQP. **Timely acquisition of the requested equipment will also accelerate the careers of two ECRs on the team** (Woods and Genikomsou) and expand the impact of the established scholars (Fam, Hoult, MacDougall, Moore, and Take).

4. NEED AND URGENCY OF EQUIPMENT

The recent Intergovernmental Panel on Climate Change report emphasizes that human-induced climate change is affecting many weather and climate extremes in every region across the globe, and that the rate of such events will only continue to grow without immediate, rapid, and sustained reductions in GHGs. There is an urgent need to both understand the effects of climate change on our built environment and to develop novel resilient and sustainable infrastructure solutions. This proposal focuses specifically on three target areas, each of which are critical elements of our built environment, specifically buildings, bridges, and railways (see Supported Research Programs).

5. SUSTAINABILITY, ACCESSIBILIY, AND DEGREE OF UTILIZATION OF EQUIPMENT

The DIC system is highly portable and will be transported between field monitoring sites and the laboratory in durable cases. The Department of Civil Engineering has technical support staff who can operate the equipment and assist HQP with training and maintenance. The investigators on this proposal will meet bi-annually to define a schedule for use of this DIC system and manage the high demand from the many HQP who will benefit from its capabilities. Although it is expected that HQP of the applicants on this proposal will be its heaviest users to support the described research programs, it **will be accessible to HQP supervised by other faculty members in the Department** when available, which could include innovative measurement applications in the fields of geo-environmental and hydrotechnical engineering.

6. USE OF EQUIPMENT IN TRAINING OF HQP

This project will have a significant impact on the training of **a minimum of 50 HQP over the next 5 years** (22 UG, 19 MASc, 9 PhD) for both field and laboratory investigations. Each HQP trained as part of the research programs supported by this equipment will have access to: (1) **hands-on training using cutting-edge DIC equipment** to study the behaviour of civil infrastructure, (2) training in interpreting the mechanics of complex structures through study of displacement and strain fields, (3) opportunities to learn in a **collaborative multi-disciplinary training environment** where students will share knowledge and experiences related to structural and geotechnical engineering, including the study of buildings, bridges, and railways, and (4) the opportunity to **collaborate with graduate students at other national and international institutions** working on climate change effects on infrastructure.

This unique training environment and opportunity to work with a state-of-the-art, real-time DIC system will provide marketable skills for HQP and meet the growing demand for experts in the field of resilience and sustainable infrastructure. This includes advanced knowledge related to the behaviour of full-scale civil structures, an understanding of the implications of a changing climate on our built environment, and effective oral and written communication skills through dissemination of the research results at conferences and in journals, all of which are highly sought-after skills in industry and academia.

Consideration of EDI is also important in the training of HQP. Concrete practices beyond those related to the supported research programs described previously (see Page 3) include: (1) the opportunity to attend monthly seminar series lectures from a diverse group of speakers to illustrate success stories from historically marginalized groups and provide role models for HQP and (2) communication with team members about the available support resources at Queen's (e.g. WiSE for women in science and engineering, Queen's Positive Space for LGBTQ2+ students, Queen's National Society of Black Engineers, and Four Directions Indigenous Students Centre).

EQUIPMENT

Required Configuration

The discovery and innovation relating to the behaviour of existing infrastructure under the effects of climate change and the development of the next-generation of resilient and sustainable infrastructure described in this proposal are made possible through state-of-the-art applications of DIC, which requires the following system configuration:

- **Measurement field of view (FOV): 0.01 m^2 to 4 m^2**. Depending on the application, this research requires a wide range of potential FOVs. This includes measurement of strain fields over the surface of a steel rail up to displacement measurements over the length of a bridge.
- **Displacement/Strain accuracy: ± 0.05 mm (in-plane) 0.1 mm (out-of-plane) / 10 με (in-plane).** To be able to capture the distributed displacements of large-scale structures (e.g., a bridge or a building) under live loads in the field, as well as strain fields in the laboratory with sufficient resolution to accurately capture stress concentrations, interfacial stresses, and crack distributions, the displacement and strain resolutions noted above are required.
- **Sampling rate: 5 Hz.** The laboratory and field experiments described in the research are conducted under static loads or loads that do not change rapidly with time. Thus, a sampling frequency of 5 Hz is sufficient to measure the response of the described systems.
- **Processing speed: real-time.** All the research described in this proposal requires real-time processing capabilities to enable timely analysis and interpretation of the results. For field applications (e.g., the study of railways, bridges, and culverts as described in the proposal), the ability to process and analyze images in real-time will maximize potential for scientific discovery by allowing the research team to interpret the results while still present on site (something not currently possible with existing technology as collected images take weeks to months to process). In the lab, the ability to conduct additional tests based on real-time DIC results would enable the research team to gain a more in-depth understanding of structural behaviour and validate additional hypotheses that would not be possible using existing technology (e.g., discrete sensor measurements or post-process DIC results).
- **Number of measurement regions: 2.** The research described in this proposal relies on the ability to take distributed measurements at two measurement regions, which will enable the research team to capture global distributed measurements of a complete structure (e.g., a building, bridge, or culvert) and evaluate global structural response while at the same time capturing high-resolution measurements (e.g., distributed strain/stress fields) to study local structural behaviour.

Based on the required configuration, quotes for two DIC systems have been obtained, the costs of which are summarized in Table 1 and in the descriptions below:

Quote 1: Correlated Solutions VIC-3D ($149,996 CAD): The VIC-3D 9 system is a turn-key, non-contact measurement system for full-field surface shape, deformation, and strain. It has in-plane and out-of-plane displacement resolutions that depend on the size of the field of view (FOV), but for a 1×1 m FOV, is has a resulting displacement resolution of 0.005 mm. The system also has a strain resolution (down to 10 microstrain) over a measurement range from 50 to 20,000 microstrain, a maximum sampling rate of 5 Hz, and 3D full-field real-time analysis capabilities. The system also includes 2 pairs of cameras, which will enable distributed measurements for two separate regions of interest.

Quote 2: GOM ARAMIS ($148,259 CAD): The ARAMIS Optical Strain system is a 3D DIC and photogrammetry system. It has full-field optical capabilities, which includes a displacement resolution of 0.005 mm over a field of view of 1×1 m, a strain resolution of 50 microstrain over a range between 50 and

20,000 microstrain, a maximum sample rate of 25 Hz, and limited real-time analysis capabilities. The quoted system only has 1 pair of cameras, which will enable measurement of one region of interest.

Preferred Supplier

Based on the required configuration, the preferred supplier is the Correlated Solutions VIC-3D system. Although their system is slightly more expensive, it is the only system that meets all of the configuration requirements, including the ability to process and visualize DIC results in real-time and simultaneously capture 2 separate measurement regions (4 cameras total).

Table 1. Cost breakdown for requested equipment

Item	Cost (USD)	Cost (CAD) (USD×1.35)	Academic Discount (CAD)	Cost (CAD) (including 3.41% HST)
1.0 Correlated Solutions VIC-3D	-	$183,500	$38,450	$149,996 (Preferred Supplier)
2.0 GOM ARAMIS	132,000	$178,200	$34,830	$148,259

Financial Contributions: The cost of the requested equipment is within the maximum RTI contribution ($150k). It is also worth noting that Correlated Solutions has offered a special academic discount of $38,450, which is over 20% of the cost of the DIC system.

RELATIONSHIP TO OTHER SUPPORT

1. Drs Woods ($155k), Hoult ($155k), Moore ($392.5k), Fam ($255k), Take ($215k), and MacDougall ($105k) each hold NSERC Discovery Grants and Woods also holds a Discovery Launch Supplement for Early Career Researchers ($12.5k). These funds are used to support HQP salaries and funds are not available to purchase equipment. However, funds from these grants will be used to support the HQP using the requested equipment to conduct field and laboratory research on the behaviour of buildings, bridges, culverts, and railways under the effects of climate change and the development of next-generation sustainable and resilient infrastructure.
2. Drs Woods and Genikomsou hold Research Initiation Grants of $70k, which provide funds to cover miscellaneous expenses and HQP funding, which will again support the HQP who will by heavy users of the requested DIC system.
3. Drs Woods, Hoult, and Moore hold a Dean's Research Fund from Queen's University of $63k to acquire hybrid simulation equipment for the GeoEngineering Laboratory, however, there are no additional funds from that grant to support the purchase of the equipment in this proposal.
4. Dr Woods holds a Research Opportunities Seed Fund ($25k) and Research Equipment Fund ($23.9k) from Queen's, but these funds are allocated for HQP salary and purchase of a thermal camera.
5. Dr Hoult's AI for Logistics Supercluster Support Program from the National Research Council of Canada provides $285.5k to investigate the use of AI for thermal stress condition assessment of rail infrastructure and there are no funds from this grant to support the requested equipment.
6. Drs Hoult and Take hold a Transport Canada: Rail Safety Improvement Program grant that provides $295.2k to study the use of distributed sensing to detect rail-foundation deterioration issues. This grant is used for equipment (a fibre optic analyser and a set of high-speed cameras) and HQP to study rail infrastructure. But the funds cannot be used to purchase the equipment requested in this proposal.

However, there would be an opportunity to deploy the requested system in the field to support the HQP working on this research and supplement/enhance existing field monitoring capabilities.

7. Dr MacDougall's NSERC Collaborative Research and Developments Grant provides $112k to study the optimization of oval hollow steel sections, but this funding is used for HQP salaries and materials.
8. Dr Fam is the Donald and Sarah Munro Chair in Engineering, which provides $100k from Queen's University to support HQP salaries, laboratory technician fees, and conference travel; however, there are no additional funds available to purchase the equipment requested in this proposal. However, funds from these grants will be used to support HQP using the requested equipment to conduct the described research on the behaviour of bridges using the Rolling Load Simulator (ROLLS).
9. Drs Moore, Hoult, and Brachman hold an NSERC Strategic Projects Grant for $590k to study pipe deterioration and leakage issues. The funding is used for HQP salaries and materials to investigate pipe deterioration issues and has no conceptual or budgetary overlap with the current proposal.
10. Dr Moore's Canada Research Chair in Infrastructure Engineering through the CRC program provides $1.4M in funding over seven years to cover much of Dr Moore's salary and benefits. However, these funds may not be used to purchase the equipment requested in this proposal.
11. Dr Take's Canada Research Chair in Geotechnical Engineering through the CRC program provides $500k in funding over five years to cover much of Dr Take's salary and benefits. However, these funds may not be used to purchase the equipment requested in this proposal.
12. Dr Take, with Dr McDougall (UBC) and Dr Evans (Waterloo) hold an $480k NSERC CRD entitled "CanBreach (Canadian Tailings Dam Breach Research) - an integrated tailings dam breach research and technology development project". These funds are restricted to support HQP salaries and equipment exploring the breach of tailings dams in large scale physical models. No funds are available to purchase the equipment requested in this proposal.
13. Dr Take is the lead PI (with Drs Moore, Hoult, Woods and other regional, national, and international co-applicants and collaborators) has been awarded grants from the Canada Foundation for Innovation ($4,470,000) and the Ontario Ministry for Research and Innovation ($4,470,000) for the project "Climate Adaptive infraStructure Testing and Longevity Evaluation (CASTLE) Innovation Cluster". That grant does not have funding for the requested equipment, as funds in this proposal are already allocated to the construction of the facility, and the development of four major research facilities: 1) an ultra-large triaxial system for rock fill / mine waste, 2) a geotechnical centrifuge, 3) a submarine landslide tank, and 4) an articulating in-soil pipe test facility. Once operational, the large number of HQP working at these new facilities will make considerable use of the requested DIC equipment.
14. Dr Genikomsou has been awarded grants from the Canada Foundation for Innovation ($150,000) and the Ontario Ministry for Research and Innovation ($150,000) for the project "Seismic Behaviour of Retrofitted Continuous Concrete Slabs". That grant does not have funding for the requested equipment, as funds in this proposal are already allocated to the development of a facility for multi-axial cyclic testing of reinforced concrete slabs. However, the HQP working with this new facility will make considerable use of the requested DIC equipment to measure 3D displacements and high-resolution strain distributions on innovative low carbon concrete slabs.