FRP

Fiber Reinforced Polymers

# International

Summer 2002

## Notable Research Activity

### The University of British Columbia

Prof. Nemkumar Banthia of the Department of Civil Engineering at the University of British Columbia has pioneered an innovative technique of structural strengthening using sprayed fiber reinforced polymeric composites. In this technique, very high performance fiber reinforced polymer is sprayed on the surface of concrete at a high velocity such that a well compacted and well bonded composite with high strength and stiffness is formed on the surface of concrete. The process uses high performance fibers (glass, carbon, or aramid), and durable polymeric resins.

The team has developed appropriate composites for structural strengthening and repair and has developed bonding agents that ensure a long-lasting bond. Initially, one of the major difficulties was a high fiber rebound during shooting. By carrying out extensive studies of fiber kinematics using high-speed photography and by modeling fiber-substrate interaction, the team has been able to substantially reduce the rebound of fibers. After significant process optimization, full-scale channel beams were tested to assess the structural response of the spray.

Figure 1: Spray Operation

Dr. Nemkumar Banthia

In September 2001, the Safe Bridge on Vancouver Island became the first bridge of its kind to undergo strengthening using the spray technique. This technique was recently awarded the Earth Science Systems Research Award at the American Society of Civil Engineers' 9th International Conference on Structural Faults and Repairs.

NSERC will showcase this research in its 2002 Performance Report to the Canadian government and on its web site.

**For more information, please contact:**
**Dr. Nemkumar Banthia,**
**banthia@civil.ubc.ca**

Figure 2: Safe Bridge, Duncan, British Columbia

### In This Issue

# Applications

## • FRP Materials for Manure Storage Facilities

Environmental concerns about the integrity of manure storage facilities have been raised in many regions of Canada. The commonly used concrete structures deteriorate at an alarming rate because the reinforcing steel corrodes. A large-scale experimental program was conducted at the University of Manitoba under the auspices of ISIS Canada to investigate the suitability of innovative design procedures for reinforced concrete manure storage tanks using FRP as an internal or external reinforcing element. The work was focused on steel rebar (the reinforcement currently used in all designs for manure tanks) and on three types of GFRP (C-BAR™, ISOROD, and GFRP spray composite). Two experimental structural designs were investigated. In the first design, the reinforced concrete specimens were not covered with any protective materials, whereas GFRP composite was used in coating the reinforced concrete specimens in the second design. The effects of the time and conditions of exposure (such as maintaining relatively high initial aggressiveness of the manure and using a wet/dry cycle) on the physical (microstructural) and mechanical properties (tensile and flexural strengths) were investigated for each structural design. The results of this study suggest that the GFRP has a higher resistance to degradation than steel in a manure environment and is an appropriate material to replace steel reinforcement in the construction of the reinforced concrete storage tanks.

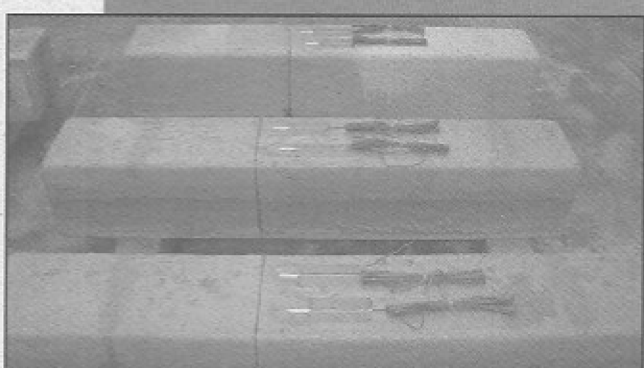


*Figure 3: Reinforced concrete beams sprayed with GFRP composite after 12 months exposure to a manure environment*

**For more information, please contact:**
**Dr. Maria Onofrei, conofrei@shaw.ca**

## • Assessing the Durability of GFRP Reinforcement through Continuous Monitoring

An aged timber crib wharf partially collapsed in the community of Hall's Harbour, Nova Scotia. The rehabilitation project resulted in a 40 m section of the breakwater being reconstructed using GFRP reinforcement. Fabry-Perot fiber optic sensors bonded to the GFRP have been remotely monitored via phone lines since September 2000. The project established the ability of this technology to be used in harsh marine environments. Research efforts are focusing on using the continuous strain data from projects such as this to assess the durability of the GFRP in situ.

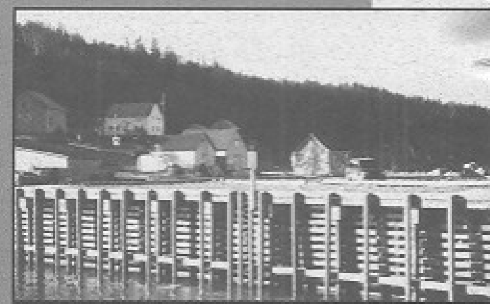


*Figure 4: Rehabilitated section of Hall's Harbour wharf*

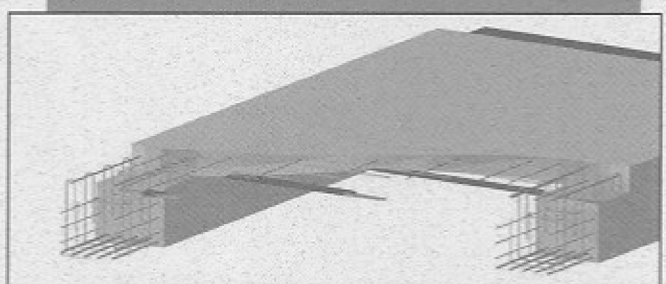


*Figure 5: Steel-free precast panels used in Hall's Harbour*

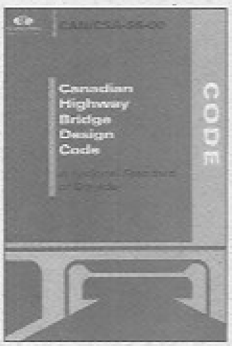
**For more information, please contact:**
**Dr. John Newhook, john.newhook@dal.ca**

## • Strengthening the Roof System of the Calgary Saddle Dome Using Fiber Reinforced Polymers

As part of the preparations to invite the Winter Olympics to Calgary in 1988, the Saddle Dome, an Olympic ice stadium, was built in 1984. The roof of the circular plan stadium has a saddle shaped

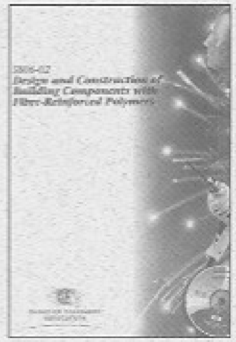
*Figure 6: Saddle Dome*

# Code Development




**Canada Highway Bridge Design Code**
A National Standard of Canada CAN/CSA-S6-00

Available from CSA International at www.csa.ca

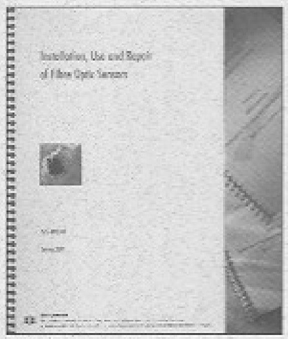


**Design and Construction of Building Components with Fibre-Reinforced Polymers**
S806-02

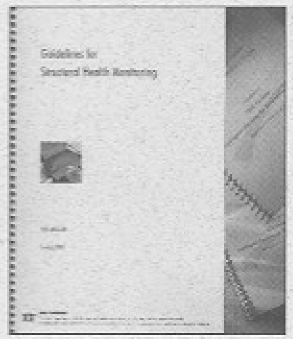
Available from the Canadian Standards Association at www.csa.ca

# ISIS Canada Design Manuals

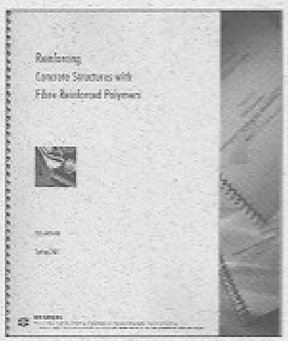
1. Sensor Technology



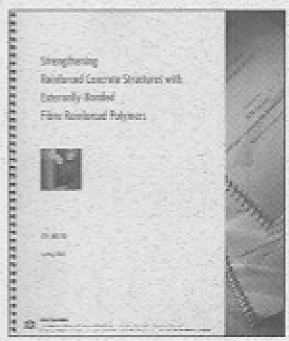
2. Structural Health Monitoring



3. Concrete Reinforced with FRPs

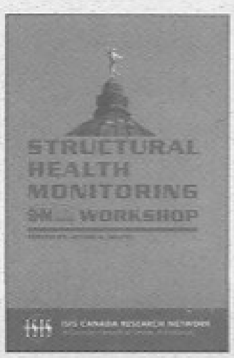


4. Rehabilitation with FRPs



ISIS Canada Design Manuals are available by ordering online at www.isiscanada.com

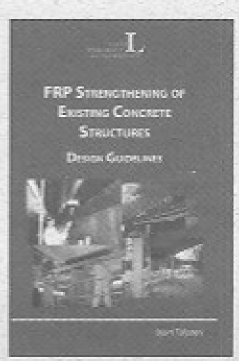
# Publications




**Proceedings of the First International Workshop on Structural Health Monitoring of Innovative Civil Engineering Structures**

Edited by Aftab A. Mufti

Available by ordering online at www.isiscanada.com




**FRP Strengthening of Existing Concrete Stuctures - Design Guidelines**
by Björn Täljsten

To order a copy please contact:
Carina Hannu
Division of Structural Engineering
Luleå University of Technology
SE-971 87 Luleå Sweden

by email: carina.hannu@ce.luth.se

## • Seismic Rehabilitation of Bridge Piers: Pathways to a Solution

Recent earthquakes in urban areas have demonstrated the vulnerability of some reinforced concrete structures to withstand seismic loads. The most common retrofit technique implemented to date to prevent column failure is steel jacketing. Nowadays, the innovative use of non-traditional materials, such as FRPs, opens the doors to a new era in the civil engineering field. The objectives of the University of Sherbrooke's ISIS research project are to optimize a reinforcement method of bridge columns with FRPs and to evaluate the increase in earthquake resistance by means of pseudo-dynamic testing.

*Figure 17: Bridge in Ste-Anne-de-Beaupré, Quebec selected for upcoming laboratory test*

The design of a large-scale model of a bridge pier is currently underway and this model will be tested in the Earthquake Engineering and Structural Dynamics Research Centre reaction wall facility at the University of Sherbrooke. Those columns will then be rehabilitated with FRPs and subjected to simulated earthquake loading with a pseudo-dynamic method. This method consists of solving the equation of motion by numerically simulating the inertia and damping forces and measuring on-line the non-linear restoring forces.

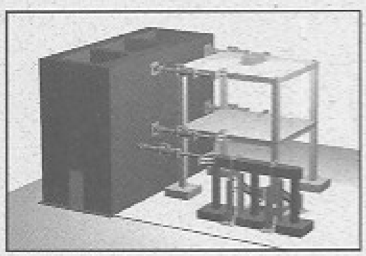


*Figure 18: Upcoming test setup*

**For more information, please contact:**
**Dr. Patrick Paultre, Patrick.Paultre@U.Sherbrooke.ca**

## • Strengthening of Salvaged Timber Stringers

An experimental program is being conducted at the University of Manitoba to strengthen full-size creosote-treated timber stringers using GFRP sheets. Various strengthening schemes are being investigated as a means of increasing the load carrying capacity of timber stringers in shear and flexure. The sheets are applied at the ends of the beam in either 45 degree or 90 degree to the axis of the beam. The beams have pre-existing cracks and splits and the sheets prevent these defects from propagating further into the stringer.

The beams were tested in three-point bending with loading point at a quarter span to develop high shear stresses at the near support only. Early results indicate that the use of GFRP sheets increases the strength of the stringers and prevents shear failure.

The research is sponsored by the Manitoba Department of Transportation and Government Services, ISIS Canada and the University of Manitoba.

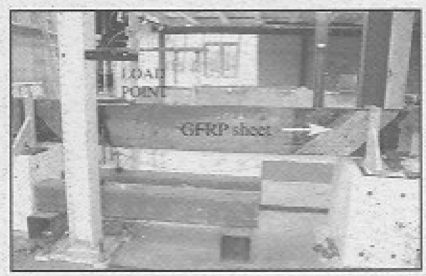



*Figure 19: Beam Testing*

**For more information, please contact:**
**Dr. Dagmar Svecova, svecovad@cc.umanitoba.ca**

# Theses

Amin, M., "An Integrated Vibration Based Health Monitoring System," Ph.D. Thesis, Carleton University, March 2002. Supervised by Drs. J. Humar and Y. Soucy.

Georgiades, T., "Experimental and Analytical Studies of Smart Composite Reinforcements and Structures." Ph.D. Thesis, Dalhousie University, May 2002. Supervised by Dr. A. Kalamkarov.

Monkman, J. "Field Assessment of Monitoring Systems and Innovative Materials in Hall's Harbour Wharf," M.Sc. Thesis, Dalhousie University, May 2002. Supervised by Dr. J. Newhook.

Ping, L. "Characterization and Application of Optical Fibers," Ph.D.Thesis, University of Ottawa, January 2002. Supervised by Dr. X. Bao.

In the second phase, numerical models are being developed to simulate fire-exposed FRP-plated beam-slab assemblies. Full-scale fire tests on FRP-plated beam-slab assemblies are planned for 2003, and also at the NRC's IRC Labs in Ottawa.

**For more information, please contact:**
**Dr. Mark Green, greenm@civil.queensu.ca**

### • Concrete Filled FRP Tubes as Piles

ISIS sponsored research is being conducted at the University of Manitoba on the effect of different loading conditions on concrete filled FRP tubes due to its novelty. In order to study the effect of driving stresses on the system, mechanically spliced and non-spliced 13.7 m piles were driven into the ground, extracted and cut into 6 m and 0.3 m pieces. Tests are being conducted on the 6 m pieces to

*Driving* *Drilling* *Extraction*

*Figure 14: Driving and extraction of piles*

estimate the damage during the driving process on the overall behavior of the system, and on the 0.3 m pieces for the effect on the individual components. The preliminary results of these tests show very little damage to the concrete and the tubes. Plans are also being made for studying the cyclic behavior of the tubes under reversed bending.

**For more information, please contact:**
**Dr. Aftab Mufti, muftia@cc.umanitoba.ca**

### • Static Response of FRP Strengthened Sawn Timber and Glulam Beams

A study at Dalhousie University examined the response of sawn timber and glue laminated (glulam) beams reinforced with fiber reinforced

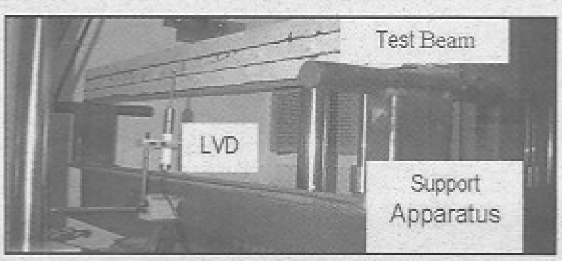



*Figure 15: Typical test set up*

polymers subjected to static loading. The glulam beams consisted of S-P-F structural lumber with and without finger-joints. Both Kevlar and glass reinforced epoxy FRP plates were used as reinforcement. Different geometrical arrangements of the FRP were also tried. The influence of FRP laminate fiber orientation; the integrity of the International Conference of Building Officials (ICBO) design guidelines; and the effect of support confinement on the ends of FRP reinforcement were all investigated.

**For more information, please contact:**
**Dr. Farid Taheri, farid.taheri@dal.ca**

### • Retrofitting of a Specialized Structure with FRP

A 15-story apartment building in Toronto was damaged due to the settlement of the foundation. The building was thus subjected to a load approximately similar to a slow earthquake and required retrofitting to enhance its ductility in addition to strength. An extensive study was undertaken which included monitoring, surveying, analysis and testing of near full-scale models of slabs, beams and columns. Repair schemes using CFRP were developed and implemented on beams and columns on the ground floor about three years ago. In excess of 300 square meters of CFRP was used. Repair of perimeter foundation walls with FRP is planned in the next few months.

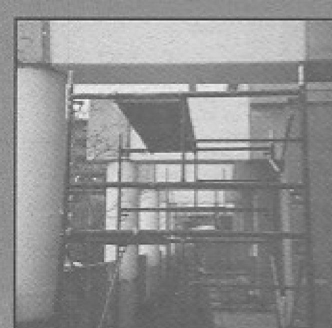


*Figure 16: Retrofitting of a specialized structure with FRP*

**For more information, please contact:**
**Dr. Shamim Sheikh, sheikh@civ.utoronto.ca**

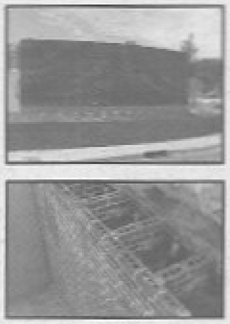


*Figure 10: FRP post-tensioned walls at the University of Calgary*

was carried out with stainless steel anchors developed with ISIS funding. The 8 mm leadline tendons were stressed to 65% of ultimate strength (eccentric) or less (concentric). Both walls have been instrumented with strain gauges and thermocouples on the CFRP tendons and the brickwork. Selected weepholes will be widened slightly to permit periodic assessment with a humidity gauge.

Monitoring is expected to reveal interesting thermal behavior especially in the curved wall with its south facing parapet and north facing full height.

**For more information, please contact:**
**Dr. Nigel Shrive, shrive@acs.ucalgary.ca**

## • Effect of Variation in Epoxy Adhesive Properties

In this research conducted at Concordia University, the effect due to the variation of epoxy adhesive properties and of variation in operating conditions on the performance of concrete reinforced by bonding with composites was examined.

**For more information, please contact:**
**Dr. Suong Van Hoa,**
**hoasuon@vax2.concordia.ca**

## • Distributed Optical Fiber Sensing for Concrete Structure

In August 2001, a FRP bridge deck in Rollinsford, New Hampshire was fully constructed and prepared for preliminary strain testing of heavy loads, and was the first bridge in North America to be completely reinforced with CFRP material. It is believed that this bridge will outlast existing steel-reinforced bridges, as CFRP does not suffer structurally from corrosive processes. The load test was performed using a 34.02 tonne dump truck, which was parked near the bridge center. The optical fibers used for strain measurements were mounted on CFRP grids, which were embedded within the concrete surface of the bridge deck several months earlier. This research was performed in collaboration with Dr. Robert Steffen and his students from the University of New Hampshire and the New Hampshire Department of Transportation (NHDOT). Dr. Brahim Benmokrane and his team from the University of Sherbrooke were also involved during the integration of the fiber optic sensors in the CFRP NEFMAC grids.

*Figure 11: Dump truck parked on center of Rollinsford bridge deck*

*Figure 12: Layout of CFRP grids prior to the final concrete pour*

**For more information, please contact:**
**Dr. Xiaoyi Bao, xbao@science.uottawa.ca**

## • Can FRP Take the Heat?

The fire performance of FRP systems for structural engineering applications must be evaluated prior to widespread implementation. A joint project of ISIS Canada, Queen's University, the National Research Council of Canada (NRC), and industry partner FYFE Co. is being conducted to:

- Experimentally evaluate the behavior in fire of FRP-reinforced, confined, and strengthened concrete
- Investigate techniques to improve the fire performance of concrete members incorporating FRP
- Develop and validate numerical models to predict the members' structural behavior in fire
- Provide design guidance regarding fire behavior based on experimental data and numerical modeling

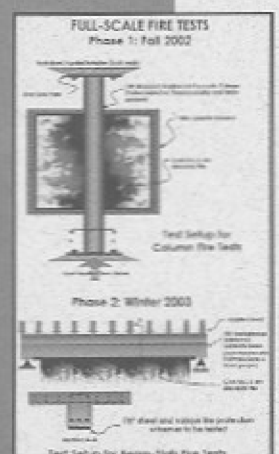



*Figure 13: Full scale fire tests*

In the first phase of the project, numerical models to simulate fire exposure of FRP-confined concrete columns and FRP bar-reinforced concrete slabs have been developed. These models are currently being validated against results from full-scale fire resistance tests on FRP-reinforced concrete members conducted at the NRC's Institute of Research in Construction (IRC) Labs in Ottawa, Canada.

surface that is mathematically described as a hyperbolic paraboloid.

Circumferential compressive stresses in the ring beam due to pre-tensioning, lightweight concrete used in the roof panels, and different loading conditions have resulted in creep effects. Circumferential creep in the ring beam induces radial loading on the roof structure resulting in compressive stresses in the roof panels.

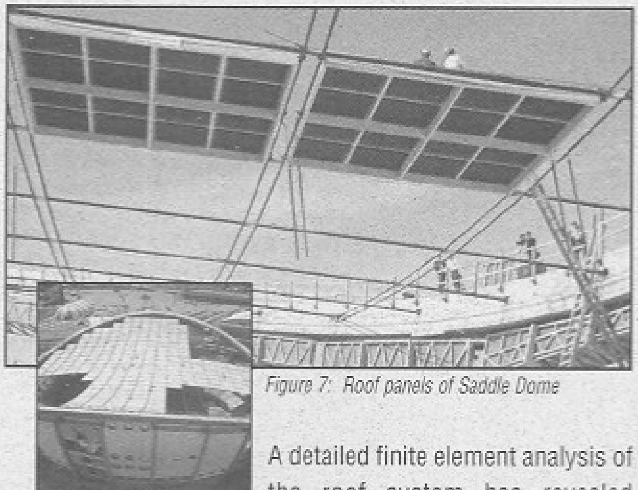


*Figure 7: Roof panels of Saddle Dome*

A detailed finite element analysis of the roof system has revealed specific roof panels require strengthening. Alternatives included CFRP sheets and strips, GFRP sheets or bars, and steel plates.

All FRP strengthening alternatives were designed according to ISIS Canada design guidelines (ISIS Canada, 2000). Major strengthening constraints include a technique that can be carried out at the interior height of the roof without disturbing activities in the Saddle Dome.

In collaboration with Stantec Consulting Ltd., ISIS Canada will examine the effects of strengthening the roof panels that are subjected to incremental compressive stresses at the University of Manitoba. Combining FRP strengthening techniques and ISIS Canada's expertise will ensure that a modern architectural symbol in Canada is preserved.

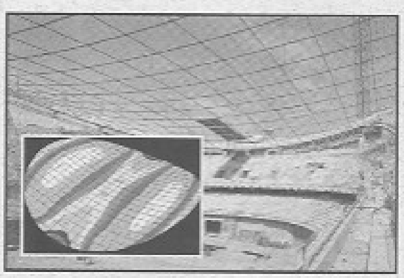


*Figure 8: Finite element model*

**For more information, please contact:**
**Dr. Gamil Tadros, gtadros@telus.net**

# Research

## • ISIS Sherbrooke-PWRI Japan Exposure Sites for the Long-Term Durability Assessment of FRP Rehab Systems

The ISIS Sherbrooke Research Group on FRP Rehabilitation, in collaboration with the Public Works Research Institute of Japan (PWRI), is investigating the long-term durability of FRPs in adverse climatic conditions. An extensive research program has been established that combines long-term exposure tests in different climatic conditions, correlations with accelerated ageing, and the development of FRP deterioration models.

*Figure 9: University of Sherbrooke's exposure site for FRP rehab materials.*

The FRP exposure program was initiated over five years ago. Various series of identical specimens have been fabricated and installed at three different exposure sites: two located in Japan, and one in Canada. The Canadian site is on the University of Sherbrooke campus, approximately 150 km east of Montreal, where very harsh winter conditions can exist for up to six months a year. Specimens at the three sites include: GFRP and CFRP laminates, with unidirectional and bi-directional fibers; epoxy plates; and concrete cylinders and beams wrapped with FRPs. Specimens from the three exposure sites are being recovered and tested according to a pre-established research schedule.

**For more information, please contact:**
**Dr. Pierre Labossière,**
**Pierre.Labossiere@USherbrooke.ca**

## • FRPs Post-Tension Masonry

ISIS-funded research on post-tensioned masonry has culminated in the construction of two demonstration diaphragm walls on the University of Calgary campus. One wall is 7.5 m long, 2.6 m high and curved on a 7.5 m radius. This wall retains soil for half its height with the remainder being a parapet for an access ramp. Concentric post-tensioning was sufficient to resist the loading. The second wall is straight and retains soil for its full height, requiring eccentric post-tensioning. Post-tensioning

## Conferences

**SPIE's 10th Annual International Symposium on Smart Structures and Materials + 8th Annual International Symposium on NDE for Health Monitoring and Diagnostics,** March 2-6, 2003, San Diego, CA, USA, www.spie.org/info/ss

**ACI Convention,** March 30 - April 4, 2003, Vancouver, Canada, www.aci-int.net

**JEC Composites Show + European SAMPE Conference,** April 1-3, 2003, Paris, France, www.globalcomposites.com/jecshow/jec2.html or www.sampe-europe.org

**ISIS Canada 8th Annual Conference,** April 30 - May 2, 2003, Vancouver, Canada, www.isiscanada.com

**SAMPE 2003 - 48th International SAMPE Symposium & Exhibition (ISSE #48),** May 11-15, 2003, Long Beach, CA, USA, www.sampe.org

**6th International Symposium on FRP Reinforcement for Concrete Structures (FRPRCS 6), Singapore,** July 8-10, 2003, http://courses.nus.edu.sg/course/cvetankh/internet/frprcs6

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Dept. of Civil Engineering
Room 227A Engineering Bldg.
University of Manitoba
Winnipeg, Manitoba
Canada R3T 5V6


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