ABSTRACT

Fiber-reinforced elastomeric isolators (FREI) are a relatively recent development in base isolation research. Consisting of layers of elastomer and fiber cloth, FREI can be cut to size from a larger sheet into any desired size or shape. Compared to traditional isolators reinforced with steel shims, FREI can potentially provide cost savings and allow for a large reduction in weight. FREI have been tested extensively to evaluate their behavior under lateral, vertical and rotational deformation, including combinations of the three deformations simultaneously. Results from these studies have shown FREI to be a viable option for use in both buildings and bridges. Throughout North America, bridges are built in a wide array of climates, with temperatures in some regions reaching extreme lows. Isolators installed in these bridges must be able to perform adequately at low temperatures. A recent experimental study was completed on unbonded FREI (U-FREI) subjected to low temperature conditioning. Specimens were held at temperatures as low as -37°C for as long as 28 days. Results from this research indicate adequate performance at low temperatures was achieved. Using these results, an existing numerical model for the behavior of U-FREI has been modified to account for the effect of low temperature conditioning. This updated model will be used in a future study to simulate a bridge located in a cold, northern climate that is isolated with unbonded FREI.

Numerical Model for The Response of Unbonded FREI at Low Temperatures

A. Sciascetti¹ and M. Tait²

ABSTRACT

Fiber-reinforced elastomeric isolators (FREI) are a relatively recent development in base isolation research. Consisting of layers of elastomer and fiber cloth, FREI can be cut to size from a larger sheet into any desired size or shape. Compared to traditional isolators reinforced with steel shims, FREI can potentially provide cost savings and allow for a large reduction in weight. FREI have been tested extensively to evaluate their behavior under lateral, vertical and rotational deformation, including combinations of the three deformations simultaneously. Results from these studies have shown FREI to be a viable option for use in both buildings and bridges. Throughout North America, bridges are built in a wide array of climates, with temperatures in some regions reaching extremes. Isolators installed in these bridges must be able to perform adequately at low temperatures. A recent experimental study was completed on unbonded FREI (U-FREI) subjected to low temperature conditioning. Specimens were held at temperatures as low as -37°C for as long as 28 days. Results from this research indicate adequate performance at low temperatures was achieved. Using these results, an existing numerical model for the behavior of U-FREI has been modified to account for the effect of low temperature conditioning. This updated model will be used in a future study to simulate a bridge located in a cold, northern climate that is isolated with unbonded FREI.

Introduction

Fiber-reinforced elastomeric isolators (FREI) employ carbon fiber cloth for the shim material. It was found that by using fiber cloth with an elastic modulus on the same order of magnitude as the steel shims, FREI can achieve more than adequate vertical stiffness [1, 2]. The increase in shim flexibility due to fiber cloth having less flexural rigidity has been shown to not significantly alter the horizontal stiffness of bonded FREI [3]. In addition, this flexibility allows for a rollover mechanism to occur when the isolator is used in an unbonded application. An unbonded FREI (U-FREI) is not fastened to the supported structure or foundation, it is simply placed between them. The rollover mechanism allows the isolator to exhibit a reduction in lateral effective stiffness at lower lateral displacements, but increase in lateral stiffness at much larger displacements [4]. With small lateral deformation, the isolator begins to “rollover” onto its originally vertical faces. When the vertical faces become completely horizontal, full rollover

¹Graduate Researcher, Dept. of Civil Engineering, McMaster University, Hamilton, ON (sciascan@mcmaster.ca)
²Department Chair, Dept. of Civil Engineering, McMaster University, Hamilton, ON

occurs, which is associated with an increase in lateral effective stiffness. Rollover has been shown to be influenced by the aspect ratio (the ratio between the width and total height) of the isolator. It was found that aspect ratios greater than approximately 2.5 result in positive lateral tangential stiffness throughout U-FREI hysteresis loops and have been referred to as a stable unbonded FREI (SU-FREI) [5, 6].

A recent study examined the lateral response of U-FREI when subjected to low temperatures [7]. This research was completed to begin investigating the effects that low temperatures have on elastomers and how U-FREI are affected. Many previous studies have found that elastomers exhibit stiffness increases with a decrease in temperature and suggested two mechanisms to describe the stiffness increases [8, 9, 10, 11] The first mechanism is called instantaneous thermal stiffening and is dependent only on the ambient temperature. When the ambient temperature is decreased, the stiffness increases rapidly. The second mechanism is called low temperature crystallization and is both temperature and duration dependent. The stiffness slowly increases at low temperatures as time passes. This is because the elastomer’s structure transitions into a semi-crystalline state as nucleation and crystal growth processes occur [12]. Crystallization has been found to cause larger increases in stiffness in neoprene elastomer compounds compared to the smaller increases in stiffness associated with natural rubber compounds [9, 11]. This study aims to provide a numerical model to describe the response of U-FREI when affected by these two mechanisms.

Test Specimens

In total, 10 U-FREI specimens were manufactured from three larger pads in the Applied Dynamics Laboratory at McMaster University. Each pad was formed from seven layers of natural rubber that alternate with six layers of bi-directional carbon fiber cloth. The rubber has a shear modulus of approximately 0.85 MPa with a durometer hardness of 55. The two outermost layers of each pad were half the thickness of the other layers. A heat activated bonding agent was used to hot-vulcanize the rubber layers to the fiber cloth. Each pad was cut into four ¼ scale specimens using a band saw, with the dimensions being 64 mm x 64 mm x 19 mm and a total height of rubber equal to 18 mm. The resultant aspect ratio of each specimen was 3.37.

For each pad, one specimen was kept at room temperature, approximately 20°C ± 5°C, in order to allow comparisons among U-FREI from different pads. From the first pad, the three remaining specimens were placed in a freezer for durations of a single day. One specimen was held at -18°C, one at -26°C and the final specimen from the pad was held at -37°C. This was repeated for the second pad, but for a conditioning duration of 14 days. Only one specimen from the third pad was placed in the freezer and it was conditioned at -37°C for 28 consecutive days. These temperatures and duration were taken from the AASHTO Standard Specification for Plain and Laminated Elastomeric Bridge Bearings [13]. The FREI specimens conditioned for 14 days at -18°C or -26°C correspond to the conditioning required for a Grade 2 or Grade 3 bearing, respectfully. The single FREI subjected to 28 days at -37°C corresponds to the Grade 5 bearing conditioning requirement.
Test Setup and Procedure

Each U-FREI was tested in a setup that was constructed for the purpose of applying lateral, vertical and rotational displacements to elastomeric isolators. As shown in Fig. 1, the test setup consists of a L-shaped reaction frame that provides the support for three actuators and the pedestal. The large column section of the pedestal allows load to be transferred to the base from the loading platens that are fixed on top. Between the two platens are two, three-axis load cells that are used to record vertical and lateral load. An insert containing a single specimen is attached to the upper platen and the loading beam. The surfaces that make contact with the specimen are steel plates that have been roughened to have a coefficient of friction similar to that of concrete. The loading beam is connected to one horizontal and two vertical actuators that can be controlled independently. The vertical actuators apply vertical loads to the specimen and can also be used to apply rotations. The horizontal actuator is used to apply lateral displacements.

Previous experimental tests and research has shown that the difference in temperature between a cold specimen and a room temperature steel plate would cause a thin layer of moisture to form between the specimen and the plate [7, 14]. This was found to be capable of inducing slip during testing. As a result, the plates were cooled to at least -15°C in situ using blocks of dry ice. The dry ice released carbon dioxide as it sublimated that displaced air around the plates. In order to maintain this environment, a chamber was constructed using acrylic around the insert. Humid air was pushed out through small gaps at the top, while the heavier carbon dioxide gas filled the chamber. This chamber did not impede the movement of the loading beam.

Once a specimen reached its conditioning duration at its specified temperature, the block of dry ice was removed from the setup and the specimen was inserted. The chamber was then resealed and the test began immediately. The vertical actuators first applied load using a ramp function until the average pressure on the specimen reached 7 MPa. This pressure was maintained as the horizontal actuator laterally displaced the loading beam. The displacements were fully reversed, sinusoidal cycles of increasing amplitudes equaling a ratio of the total height of rubber \((t_r)\) in the specimen. The amplitudes were sequentially applied in sets of three cycles at each of 0.25, 0.50, 0.75, 1.00, and 1.50 of \(t_r\). Once the 15 cycles were complete, the vertical load on the
specimen was removed. The entirety of the test took less than 60 seconds.

For each test, the lateral displacement, vertical load and lateral load were recorded. This data was processed to isolate each individual cycle. From each cycle, the lateral displacements and loads were used in order to calculate the effective horizontal stiffness, the energy dissipated during a single cycle, as well as the effective equivalent viscous damping ratio. The effective horizontal stiffness, $K_{h,\text{eff}}$, was calculated by taking the slope of the line drawn through the maximum load and displacement and the minimum load and displacement in a cycle \[15\].

$$K_{h,\text{eff}} = \frac{(F_{L,\text{max}} - F_{L,\text{min}})}{(\Delta L_{\text{max}} - \Delta L_{\text{min}})}$$  \hspace{1cm} (1)

The variables $F_{h,\text{max}}$, $F_{h,\text{min}}$, $\Delta h_{\text{max}}$, and $\Delta h_{\text{min}}$ correspond to the maximum and minimum values of lateral load and the maximum and minimum values of lateral displacement. The area enclosed within the hysteresis loop was then determined in order to find the energy dissipated, $E_D$, during each cycle. Using the effective stiffness and energy dissipation in each cycle, the equivalent viscous damping ratio, $\zeta$, was calculated \[16\].

$$\zeta = \frac{E_D}{2\pi K_{h,\text{eff}} \Delta_{\text{avg}}^2} \quad \text{where} \quad \Delta_{\text{avg}} = \frac{\Delta L_{\text{max}} + |\Delta L_{\text{min}}|}{2}$$  \hspace{1cm} (2)

**Lateral Response**

The ten specimens were tested according to the procedure outline above. Each test was videotaped in order to review and confirm that slip did not occur. It was found that a small amount of slip only occurred during the test of the 28 Day | -37°C specimen at the amplitudes of 0.50, 0.75 and 1.00 $t_r$. Initial analysis of the data collected indicated that the 14 Day | -18°C and the 14 Day | -26°C specimens produced very similar results to the 1 Day tests at the same temperatures. As such, these specimens have not been included in this paper. The remaining six specimens were separated into two groups, a Temperature and a Duration data set. The Temperature data set contained the -18°C, -26°C and -37°C specimens that were conditioned for only a single day. This data set represents the effect that instantaneous thermal stiffening has on U-FREI. The second data set contained the 1 Day, 14 Day, and 28 Day specimens that were conditioned at -37°C. This data set represents the effect of crystallization on the response of U-FREI. The two data sets overlap by both containing the 1 Day | -37°C U-FREI.

The effect of instantaneous thermal stiffening on U-FREI is illustrated in Figs. 2a and 2b. The x-axis is the temperature in degrees Celsius and the y-axis is either lateral stiffness or energy dissipated normalized by the values of the corresponding 1 Day room temperature specimen at each displacement amplitude. The figure depicts the change in values for each displacement amplitude over the three temperatures. A similar trend is seen in both normalized lateral stiffness and normalized energy dissipated. As the temperature is decreased, the values in both figures increase almost linearly at each amplitude. At -18°C the stiffness and energy dissipated values at each amplitude are approximately the same. At the lower temperatures, the values over the displacement amplitudes show a reduction as the amplitude is increased, along with a greater variation in change in stiffness and energy dissipation between the displacement amplitudes. The
The largest increase in stiffness occurs at the temperature of -37°C during the 0.25 $t_r$ cycle and equals 2.2 times the room temperature value. The largest increase in energy dissipated occurs at the same cycle and equals approximately 4.2.

![Figure 2. The effect of instantaneous thermal stiffening on a) effective lateral stiffness and b) energy dissipated, both normalized against room temperature values.](image)

![Figure 3. The effect of crystallization on a) effective lateral stiffness and b) energy dissipated, both normalized against room temperature values.](image)

The effect of crystallization on U-FREI is shown in Figs. 3a and 3b. For these figures the x-axis represents the number of days that each specimen was conditioned for at -37°C. The 1 Day data points are the same as the -37°C data points from Fig. 3. It can be observed that the $Duration$ data set does not have the same linear trend as the conditioning duration is increased. The slope of each line between 14 days and 28 days is greater than between 1 and 14 days. This indicates that crystallization has an increased effect on stiffness and energy dissipation at 28 days of
conditioning. The increase in stiffness and energy dissipation can be explained by the reorientation of the elastomer’s molecular structure that occurs during crystallization. The mechanism of crystallization causes crystal growth within the elastomer. As days at the conditioning temperature of -37°C pass, more crystals grow and the elastomer transitions into a semi-crystalline state. When the specimen is then tested, the crystals must be fractured in order to accommodate the displacement amplitudes and as a result, cause a larger force to be required to shear the specimens. Energy is also dissipated during this process causing the increase that is shown in the figure. The values for the displacement amplitudes of 0.50, 0.75 and 1.00 $t_r$ are included for reference, but slip did occur during those cycles. This is evident in Fig. 4b where the 0.50 and 0.75 $t_r$ cycles at 28 days provide larger energy dissipation than at 0.25 $t_r$. The additional energy dissipation may be a result of abrasion against the roughened plates during slip.

**Isolator Model**

The data from the previous section was separated into two data sets in order to develop a numerical model capable of describing the effect of instantaneous thermal stiffening and crystallization on U-FREI. Multiple models have been previously developed to simulate the lateral response of U-FREI, but each model has only been valid at room temperature. Early models by Toopchi-Nezhad et al. [4, 17] required an iterative analysis procedure in order to achieve convergence. Each displacement amplitude had its own parameter values, which required an iterative procedure to interpolate between two amplitudes with pre-defined parameters. This limitation was later addressed by Osgooei et al. [18] with the development of the Pivot-Elastic model. It is a non-iterative model that is calibrated using effective stiffness and equivalent viscous damping values that are calculated from experimental data. It combines a bilinear Pivot model, for energy dissipation, with a non-linear elastic spring that is used to capture increases in effective stiffness that are present in U-FREI at large amplitudes. Subsequently, Al-Anany et al. [19] introduced a Takeda-Elastic model that contains fewer parameters and allowed for a more practical application in OpenSees, an Open System framework for Earthquake Engineering Simulation.

The following is a brief summary of the Takeda-Elastic Model and Al-Anany et al. [19] should be referred to if further detail is sought. The Takeda model is the hysteretic element that adds energy dissipation to the Takeda-Elastic model. Its bilinear behavior is defined using three parameters, $k_1$ to describe the initial stiffness, $k_2$ to describe the post yield stiffness, and $u_y$ to indicate the yield displacement, or the transition point between $k_1$ and $k_2$. The non-linear elastic spring is the element that is used to vary the stiffness of the model at different displacement amplitudes, in order to effectively capture the non-linear behavior of the U-FREI. This is accomplished by defining a fifth-order polynomial to model the force-displacement curve of the spring. The coefficients of the spring are $a_1$ through $a_5$ and are each unique model parameters that are determined using the values of effective stiffness and damping from experimental data. In order to ensure symmetry, the coefficients $a_2$ and $a_4$, corresponding to the powers of two and four in the polynomial, were set to zero. In total, the Takeda-Elastic model contains six parameters and is presented as follows:

\[
F_T(u) = (k_1 + a_1)u + a_3u^3 + a_5u^5 \quad \text{for} \quad u < u_y \\
F_T(u) = k_1u_y + k_2(u - u_y) + a_1u + a_3u^3 + a_5u^5 \quad \text{for} \quad u \geq u_y
\]  

(3a)  

(3b)
where $F_T(u)$ represents the force of the Takeda-Elastic model as a function of the lateral displacement, $u$, of the U-FREI. This equation can then be used to produce hysteresis loops for the modeled U-FREI and calculate effective stiffness and equivalent viscous damping.

The six parameters of the Takeda-Elastic model can be determined using a least squares regression analysis. The experimental effective stiffness and damping values are compared to the model stiffness and damping values from Eqs. 1 and 2. Once the parameters are determined, Eq. 3 provides the response of U-FREI at any displacement amplitude desired without iteration.

**Low Temperature Model**

The Takeda-Elastic model was used to model the response of each individual U-FREI provided within Figs 3 and 4. This resulted in maximum error between the experimental and model effective stiffness and damping values of 5%. These values were then used as a starting point for developing the six Takeda-Elastic model parameters into functions of temperature and duration to match the two data sets from the lateral response results. For example, the parameter $k_i$ would become a function in the form $y = mx + b$, where $y$ is $k_i$, $x$ is a variable for temperature or duration and $m$ and $b$ are coefficients to be determined. This would allow the parameters to be simply calculated by substituting any temperature between -18°C and -37°C for the variable $x$. A set of six parameters for that temperature would then be created without the need for minimizing errors using an iterative process. Alternatively, any duration between 1 and 28 days of conditioning can be substituted for $x$ and provide a set of six parameters for a U-FREI that had been conditioned at -37°C for $x$ number of days.

In order to determine the coefficients for each parameter, five Takeda-Elastic models must be solved using both data sets simultaneously. Both data sets were required since the 1 Day | -37°C specimen overlapped between the Temperature and Duration data sets. Linear regression of each parameter over the three temperatures and three durations was used to develop the equations of the lines that would describe each parameter. The errors between the experimental values and those obtained are presented in Table 1, along with the actual values that were obtained. The room temperature specimen was included for reference, but was not included in the linear regression model. In the left column, the label ‘E’ stands for the experimental values, ‘M’ for the model values, and %Δ represents the percent difference between the experimental and model values, or error associated with the model values. It can be seen that the largest error is 8% and in many cases, the error remained below 5%. Values for energy dissipation have been included as well to show that the area within the simulated hysteresis loops are also within the same limits.

The model values provided in Table 1 were obtained using the two sets of equations that were developed through simultaneous least squares linear regression. The general form of the two sets of equations are:

$$P_{\text{Temperature}} = a_{T0} + a_{T1}T \quad -18°C \geq T \geq -37°C \quad (4)$$

$$P_{\text{Duration}} = a_{d0} + a_{d1}T \quad 1 \text{ day} \geq D \geq 28 \text{ days} \quad (5)$$
where $P$ is a placeholder for any of the six Takeda-Elastic parameters, the intercept coefficients are $a_{T0}$ and $a_{D0}$ and the slope coefficients are $a_{TI}$ and $a_{DI}$ as labeled in Table 2. The table provides the actual coefficient value results from the model and can be used to describe the parameters needed to model U-FREI under the temperature and duration limits provided in Equations 4 and 5.

Table 1. Comparison of experimental and model values

<table>
<thead>
<tr>
<th>Amplitude (u/a)</th>
<th>Stiffness (N/mm)</th>
<th>Energy Dissipation (J)</th>
<th>Damping (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.25</td>
<td>0.50</td>
<td>0.75</td>
</tr>
<tr>
<td>20°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% $\Delta$</td>
<td>-1.0</td>
<td>0.3</td>
<td>0.9</td>
</tr>
<tr>
<td>-18°C 1 Day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>342.4</td>
<td>270.8</td>
<td>232.0</td>
</tr>
<tr>
<td>% $\Delta$</td>
<td>-5.0</td>
<td>-0.8</td>
<td>4.6</td>
</tr>
<tr>
<td>-26°C 1 Day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>419.3</td>
<td>315.0</td>
<td>263.2</td>
</tr>
<tr>
<td>% $\Delta$</td>
<td>5.0</td>
<td>0.1</td>
<td>4.1</td>
</tr>
<tr>
<td>-37°C 1 Day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>553.7</td>
<td>389.6</td>
<td>325.0</td>
</tr>
<tr>
<td>% $\Delta$</td>
<td>-3.6</td>
<td>-5.0</td>
<td>-4.2</td>
</tr>
<tr>
<td>-37°C 14 Days</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>944.4</td>
<td>566.2</td>
<td>428.5</td>
</tr>
<tr>
<td>% $\Delta$</td>
<td>8.0</td>
<td>1.5</td>
<td>-0.9</td>
</tr>
<tr>
<td>-37°C 28 Days</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>1735</td>
<td>845.0</td>
<td>650.0</td>
</tr>
<tr>
<td>% $\Delta$</td>
<td>-8.0</td>
<td>5.7</td>
<td>-3.1</td>
</tr>
</tbody>
</table>

*Note: Experimental = E  Model Value = M  %$\Delta$ = Percent Difference between Experimental and Model Values

Table 2. Parameters as linear functions of either temperature or duration

<table>
<thead>
<tr>
<th>$P$</th>
<th>Temperature</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$a_{T0}$</td>
<td>$a_{TI}$</td>
</tr>
<tr>
<td>$k_1$ (N/mm)</td>
<td>-3929.8</td>
<td>-3399.9</td>
</tr>
<tr>
<td>$k_2$ (N/mm)</td>
<td>52.6</td>
<td>-1.3x10^{-1}</td>
</tr>
<tr>
<td>$u_y$ (mm)</td>
<td>2.1x10^{-1}</td>
<td>9.3x10^{4}</td>
</tr>
<tr>
<td>$a_1$ (N/mm)</td>
<td>203.6</td>
<td>1.5</td>
</tr>
<tr>
<td>$a_3$ (N/mm^3)</td>
<td>-1.9x10^{-1}</td>
<td>-4.0x10^{-3}</td>
</tr>
<tr>
<td>$a_5$ (N/mm^3)</td>
<td>9.2x10^{-5}</td>
<td>-7.6x10^{8}</td>
</tr>
</tbody>
</table>

For example, if U-FREI were to be implemented in Montreal, Canada, the equations associated with the Temperature data set could be used to describe the isolators expected behavior. The Duration data set does not need to be used because Montreal exhibits short durations of temperatures that approach -37°C, but are not sustained typically for longer than a day [20]. The
temperature of -35°C could be substituting into Eq. 4 using the six sets of coefficients given in Table 2 under the heading Temperature, even though the temperature of -35°C was not explicitly tested experimentally. The resulting six parameters can be substituted into the Takeda-Elastic model and be used with a program such as OpenSees in order to evaluate the isolators seismic response for the location of Montreal. A sample hysteresis loop is shown in Fig. 4 comparing the experimental results with results obtained by using the provided parameter equations of Table 2. Lateral force on the vertical axis has been normalized by the shear modulus, $G$, and the area of a specimen, $A$. The hysteresis loops are shown for the 1 Day | -37°C specimen. The model hysteresis loops can be obtained for any temperature or duration within the limits of Eqs. 4 and 5.

![Hysteresis Loop Comparison](image)

Figure 4. 1.50 $t_1$ hysteresis loop comparison between experimental and model

**Conclusion**

When the bridges are located in cold, northern climates, the isolators must be able to withstand those low temperatures. In this study, quarter-scale unbonded fiber-reinforced elastomeric isolators (U-FREI) were dynamically tested to determine their lateral response when subjected to low temperatures for various durations. The experimental program indicated that two main data sets could be created from the results. The Temperature set contained the results of the effect of instantaneous thermal stiffening over the temperatures of -18°C to -37°C. The Duration set contained the results of the effect of crystallization over the durations of 1 to 28 days, while the temperature was maintained at -37°C.

An existing numerical model that simulates U-FREI hysteresis loops at room temperature was used in order to develop two sets of equations from the two data sets. The two sets of equations are capable of producing numerical models that describe the behavior of U-FREI for a conditioning duration of one day at any temperature between -18°C and -37°C, or at a temperature of -37°C, for any conditioning durations between 1 and 28 days. The values for effective stiffness, energy dissipation and equivalent viscous damping ratio obtained through the model are within 8% of experimentally obtained values. The model can be used to determine the lateral response of U-FREI located in cold, northern climates. A future study will use the two sets of equations provided within this paper to evaluate the seismic performance of a bridge isolated with U-FREI located in a cold, northern climate.
Acknowledgements

This research was carried out as part of the mandate of the Centre for Effective Design of Structures (CEDS) at McMaster University and is partially funded by the Ontario Ministry of Economic Development and Innovation and by the Natural Sciences and Engineering Research Council of Canada (NSERC).

References

[16] CHBDC, S6-14 - Canadian Highway Bridge Design Code 2014; Toronto, Canada: CSA.