

**Seismic Testing of
RC Concrete Squat Wall with Opening
w/o Octaform system
Vancouver, BC**



Prepared for:
Octaform Concrete Forming Systems
Vancouver, BC

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EXECUTIVE SUMMARY

This report describes the results from a series of tests conducted by the Department of Civil Engineering of the University of British Columbia on two reinforced concrete squat walls, one with, and one without the Octaform Concrete Forming System (OCFS). The dynamic load tests were conducted by placing the prototype on a shake table and subjecting it to prescribed earthquake excitations to verify their expected performance under severe shaking.

The objective of these tests was to determine whether the OCFS protects a reinforced concrete structure against cracking and spalling during a severe earthquake, and if the lateral load capacity of the wall is affected by the presence of the OCFS.

The results of the dynamic tests showed that, by comparison, the structure with the OCFS had a greater lateral load capacity, was protected against spalling, and showed a significant reduction of the amount of cracks on the surface.



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Introduction

The Octaform Concrete Forming System (OCFS) consists of slide together pre-manufactured pvc panels. The panels combine to form two finished exterior sides and a lattice interior. Once constructed, the OCFS stays in place permanently, eliminating the need for additional cladding.

Two reinforced squat walls, one bare, and one with the OCFS, were dynamically tested at the Earthquake Engineering Research Facility (EERF) at UBC on April 10th and April 19th, of 2007. The prototype was subjected to prescribed simulated ground motions at different intensities on a shake table in order to determine its performance under severe dynamic loads in comparison to the bare specimen.

The objectives of the experiment were to determine whether the OCFS protects a reinforced concrete structure against cracking and spalling during a severe earthquake and whether the lateral load capacity of the prototype exceeds that of the bare specimen.

Background

Initially, the test specimens were designed as reinforced concrete squat walls with minimum reinforcement [CSA, 2004] and a height to width ratio of 1.0. During testing, the maximum flexural and shear cracking strength of the benchmark specimen surpassed the maximum dynamic loads achievable by the newly installed EERF linear shake table. Consequently, an opening was cut in the center of each wall to reduce the effective lateral stiffness and strength of the specimens. Because of this change, the specimens were not detailed to have the reinforcement required at the corners of the opening.



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Test Specimen Description

The 28-day concrete strengths for frames, established by standard cylinder tests, were approximately 32 MPa. The yield strength of reinforcement used in both frames was approximately 400 MPa.

The wall dimensions of the specimen were 2.4m x 2.4m, with an opening in the center of 1.6m x 1.3m and a thickness of 0.10m. The bare minimum code amount of horizontal and vertical reinforcement was provided ($\rho=0.29\%$). Figure 1 shows the dimensions and the reinforcement detailing of the test specimens.

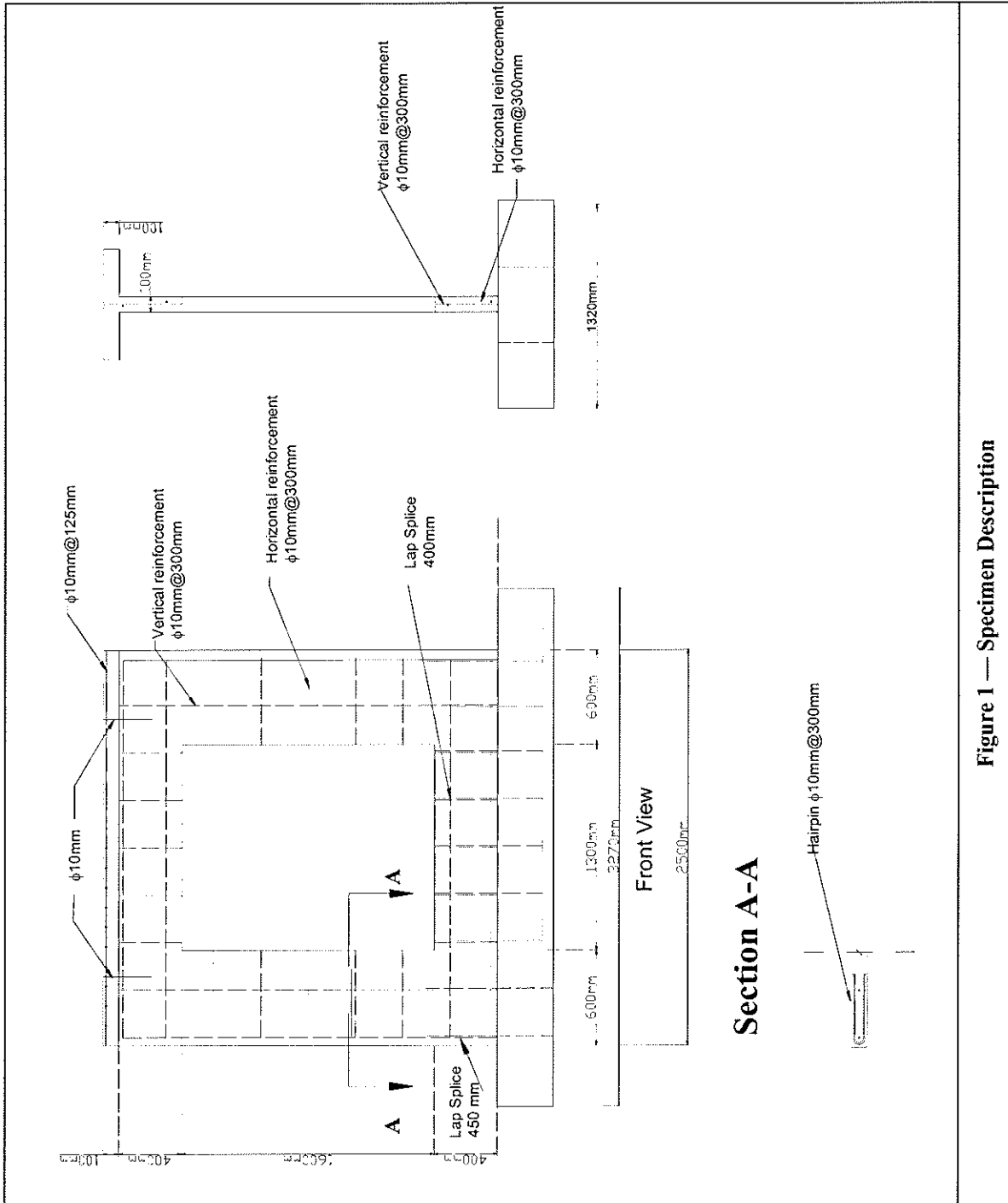
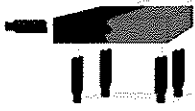
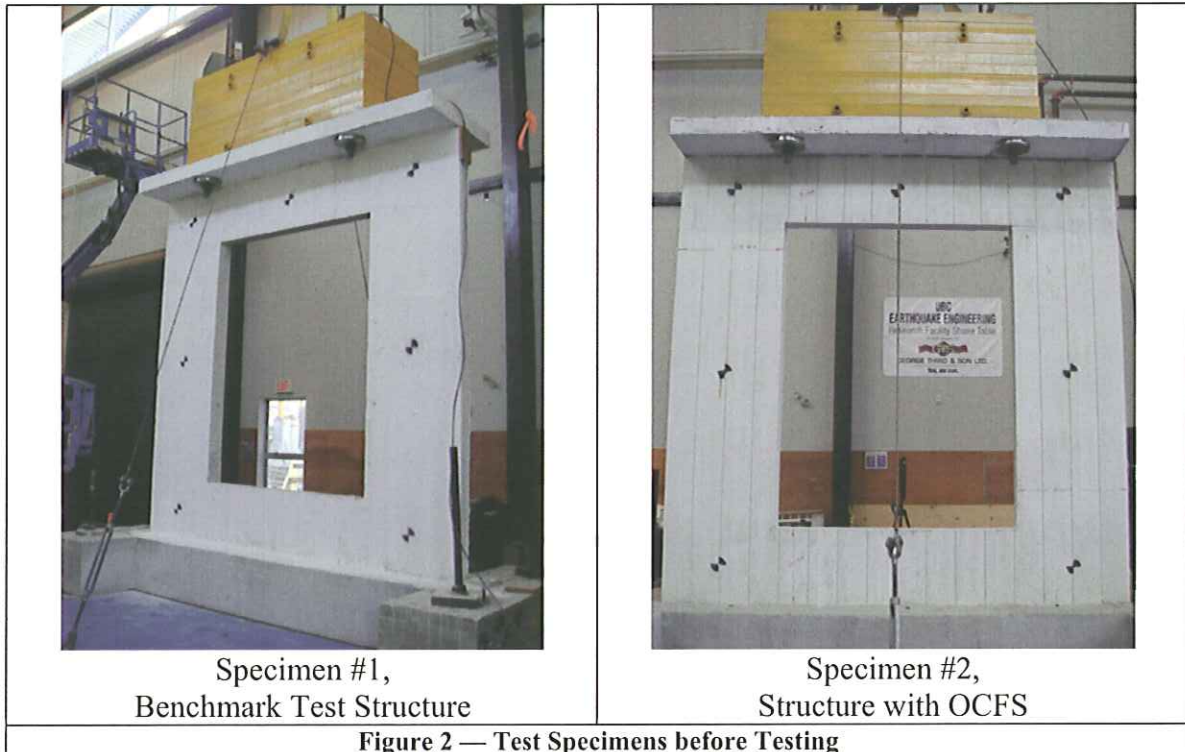


Figure 1 — Specimen Description

Test Setup

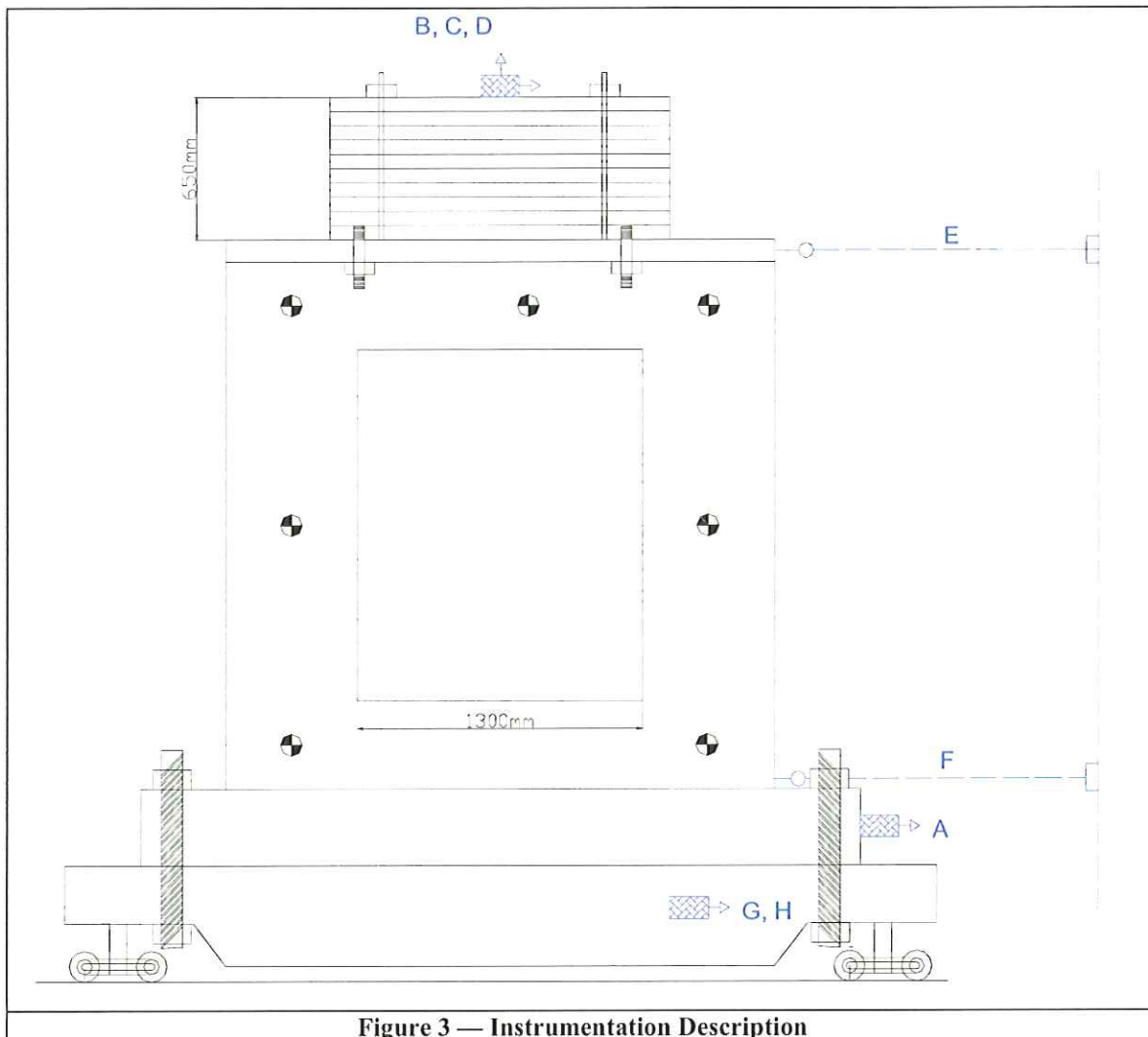
The test specimen foundation was bolted with high strength threaded steel rods to the EERF shake table frame to achieve a rigid connection. Shims were used in areas in which the base of the specimen foundation was uneven with respect to the table and a surcharge weight of 44.6kN was bolted to the slab of the specimen. Figure 2 shows images of both test specimens with test setup.



Instrumentation

The instrumentation for this experiment consisted of piezo resistive accelerometers and position transducers to measure the accelerations and the horizontal displacements of the specimen, respectively. The accelerometers were fixed to the shake table, the specimen foundation, and the top of the surcharge weight. Two position transducers were placed at the top and at the base of the specimen to measure the horizontal displacement at those

locations (see Figure 3). Table 1 provides a description of the instrumentation used for these tests.



Instrument		Channel ID	Type	Range
Uniaxial Accelerometer	A	A1D-8	Piezo Resistive Accelerometer ICSensors Model 3110	+/- 10 g
Triaxial Accelerometer	B	A3D-X	Piezo Resistive Accelerometer ICSensors Model 3026	+/- 5 g
	C	A3D-Y		+/- 5 g
	D	A3D-Z		+/- 5 g
Position Transducer	E	SP13	Celeco Cable-Extension Position Transducer Model PT101-0150-111-1110	+/-3000 mm
Position Transducer	F	SP19	Celeco Cable-Extension Position Transducer Model PT101-0150-111-1110	+/-3000 mm
LoadCell	G	LoadCell	INTERFACE LoadCell Model 1032-AFM	+/- 50 kip
Uniaxial Accelerometer	H	TAccel	Piezo Resistive Accelerometer ICSensors Model 3110	+/- 10 g

Table 1 — Instrumentation

Test Procedure

Each test specimen was subjected to the VERTEQ-II synthetically generated earthquake acceleration record [Telecordia Technologies, 1995]. This record was applied at each test with consecutively increasing amplitudes.

The calculated natural frequency obtained through an analytical model using SAP2000, [Computer and Structures Inc., 2005], for specimen 1, with the surcharge weight of 44.6KN, resulted in $F_n=18\text{Hz}$. To evaluate the performance of the test specimens, the selected record should generate similar seismic demands in comparison to the design earthquake ground motion recommended by the NBCC 2005 [NRCC, 2005]. The

VERTEQ-II record was normalized in order to conform to the Uniform Hazard Spectrum for 2% probability of exceedance in 50 years for Vancouver [Geological Survey of Canada, 2003], resulting in a peak acceleration of 0.50g. The effective duration of the VERTEQ-II was 16.0 sec and the sampling rate was 200 samples per second (sps).

In Figure 4, the VERTEQ-II 100% input waveform's acceleration, velocity and displacement time histories are plotted against the respective measured values generated by the shake table during testing.

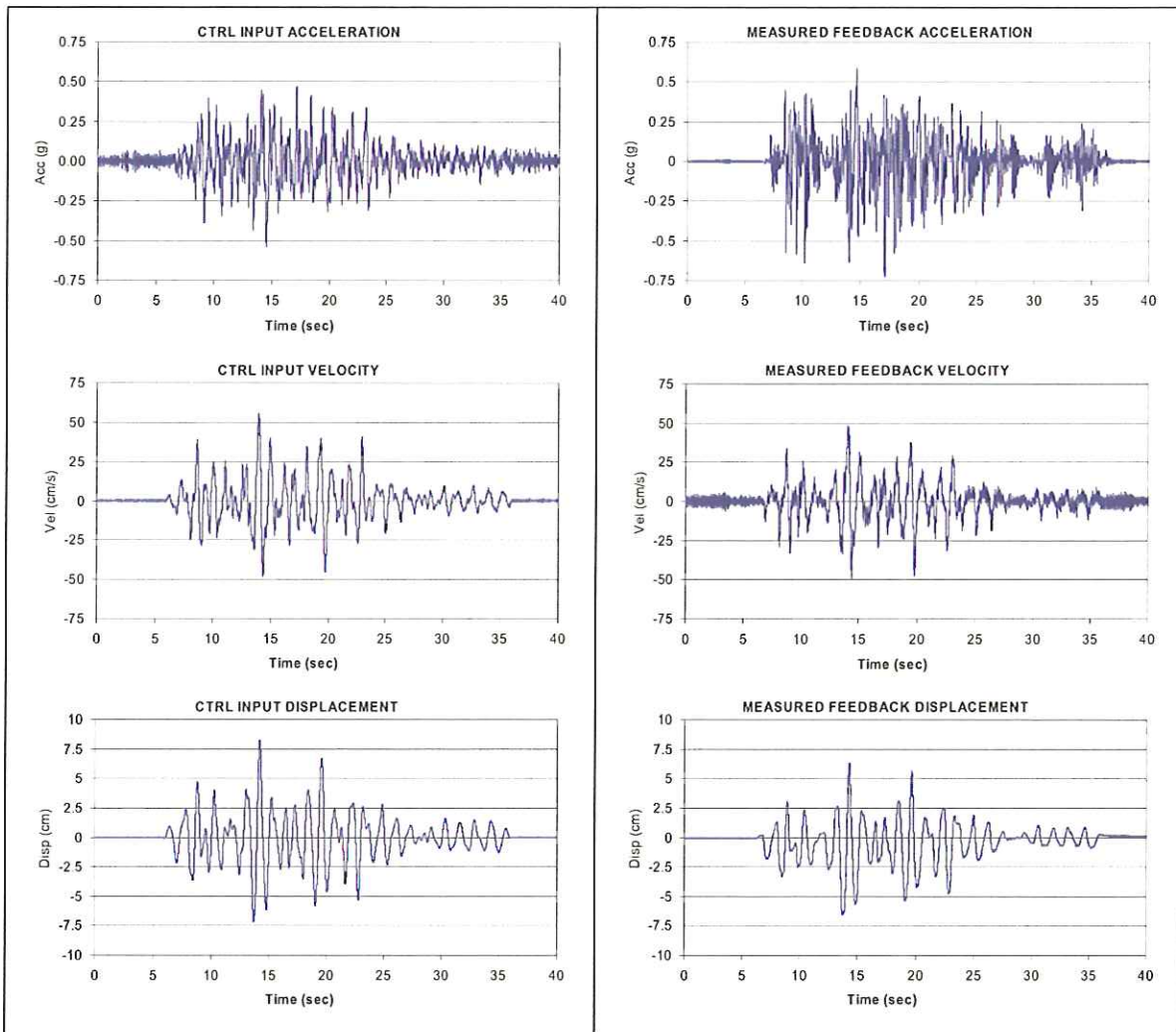


Figure 4 — VERTEQ II input and measured motion

Figure 5 below shows the acceleration response spectrum, which is plotted for the VERTEQII 100% input and measured acceleration records, as well as the UHS 2% in 50 years for Vancouver.

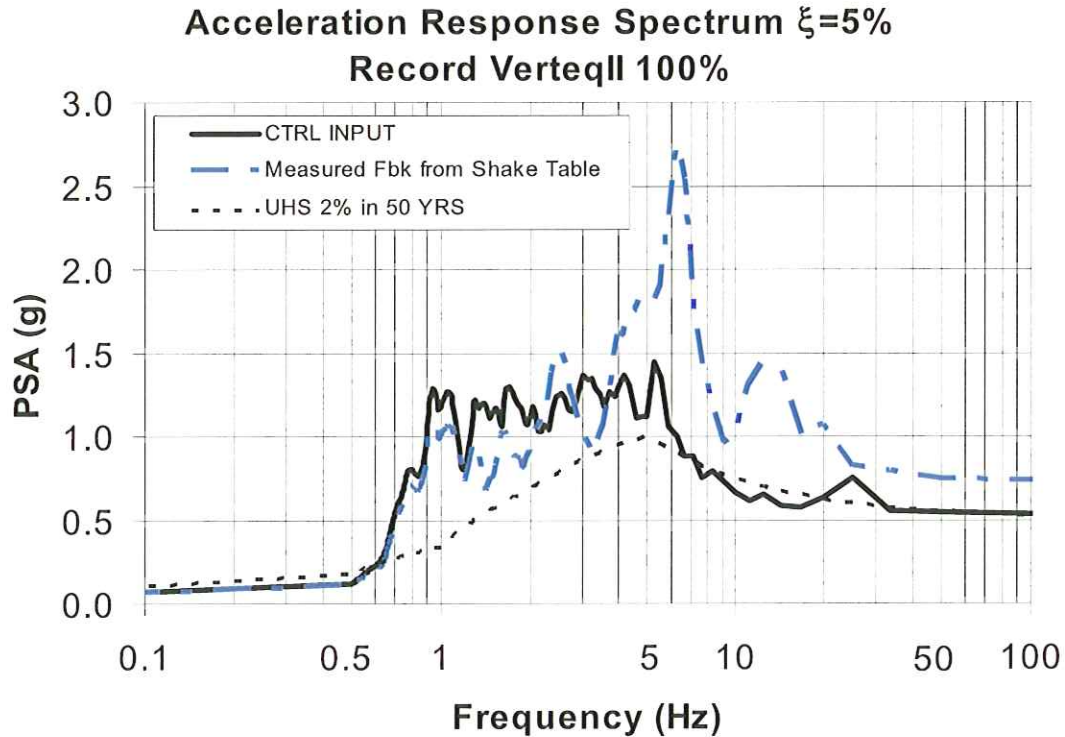


Figure 5 — Response Spectrum

Results

The benchmark specimen was tested to failure by consecutively increasing the amplitude of the VERTEQ-II record. The second specimen was then tested under the same loading sequence.

Specimen #1 (Benchmark Test Structure)

Prior to dynamic testing, an initial flexural hairline crack was observed at the mid-span of the beam (see Figure 6a). This crack was due to the surcharge weight of 44.6 KN, which was applied on the clear span of the opening (see Figure 3).

The dynamic loading tests started with the VERTEQ-II record at 25% and no damage was observed thereafter. When the amplitude of the earthquake was increased to 50% and subsequently 75%, diagonal hairline cracks developed at the lower left corner of the opening (see Figure 6b). With a further increase in amplitude to 100%, no additional cracks developed in the specimen. The record was then scaled up to 200%.

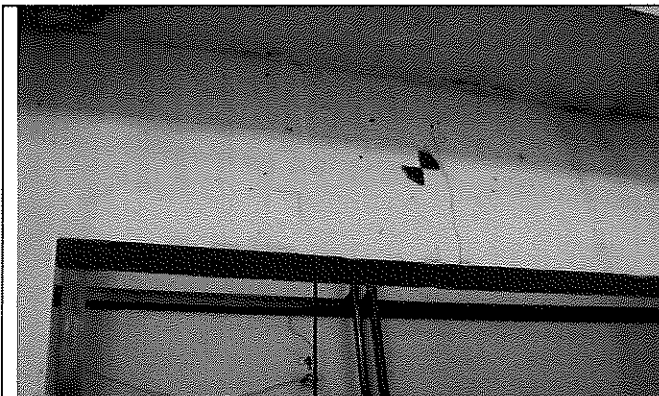


Figure 6a — Hairline crack at mid-span of beam

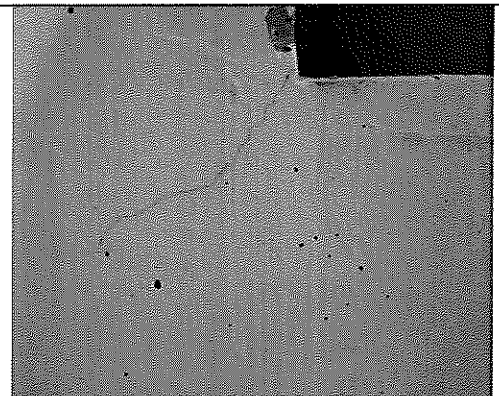


Figure 6b— Diagonal hairline crack at the corner of the opening

At 200%, the test specimen sustained dynamic loads above its maximum strength and developed severe cracking. Flexural cracks developed along the length of the columns, with the largest flexural cracks occurring at the clear span. Additional flexural cracking occurred in the beam along the mid-span and at the ends of the clear span. The width and length of existing diagonal cracks from previous dynamic loading were significantly increased, and were observed at all four corners of the opening. The crack distribution of the specimen is shown in Figures 7a and 7b. It was observed that all flexural cracks

along the span of the beam and columns coincided with the location of the vertical and horizontal reinforcement, respectively. Position transducers were disconnected after this test.

After reaching severe cracking, no further increases in amplitude for the record were performed. A sequence of two VERTEQ-II 100% records, 30 seconds apart, was conducted and this was augmented by the addition of two other Earthquake records, Llolleo (1985), and el Centro (1940), having respective amplitudes of 0.60g and 0.80g. The completion of these tests showed existing cracks opening further, but no new cracks appearing. With the aim of taking the specimen to its maximum allowable limit, a sequence of two VERTEQ-II 200% records was applied, which resulted in the collapse of the benchmark specimen.

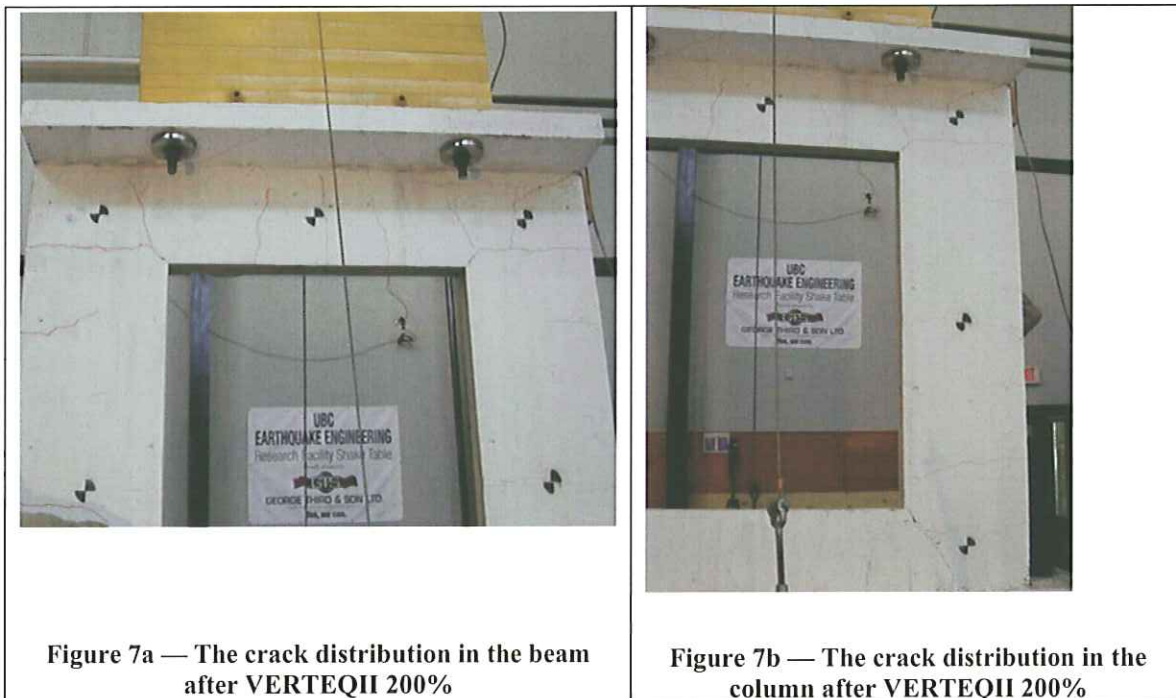
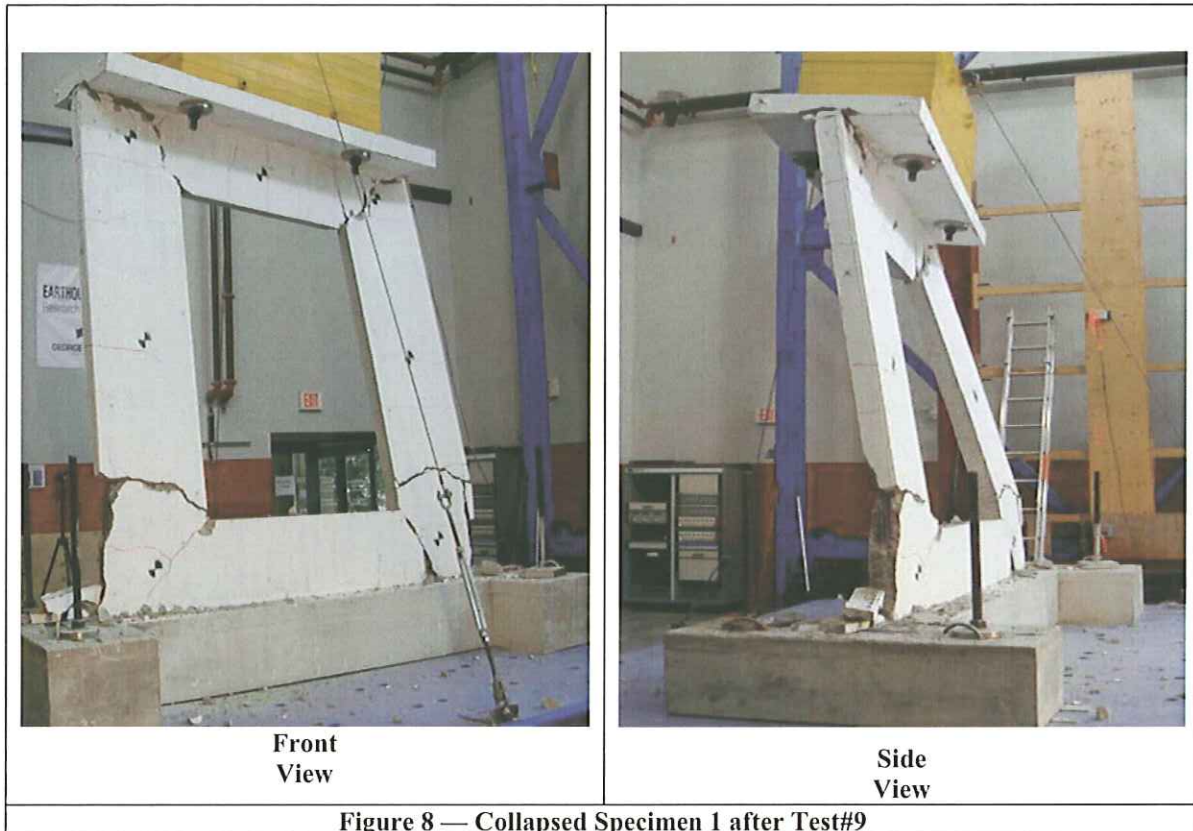


Figure 7a — The crack distribution in the beam after VERTEQII 200%

Figure 7b — The crack distribution in the column after VERTEQII 200%

The collapse occurred during the second VERTEQII 200% record, when a crack developed due to a combination of flexure and shear at the bottom of the clear length of

the left column; consequently, allowing significant rotation. When the subsequent spalling of the concrete cover occurred, this column became unstable and the specimen collapsed out of plane (see Figure 8).



Specimen #2 (Structure with OCFS)

Prior to dynamic testing, the specimen did not show any hairline cracks along the clear span of the beam. The dynamic loading followed the same order and amplitude protocol as for specimen 1. The record at amplitudes of 25%, 50%, 75%, 100% and 200% produced no observable damage. When the VERTEQ-II record at 200% showed no discernible damage, it was decided that the amplitude of the record should continue to be incrementally increased until severe cracking of specimen 2 could be observed.

At an amplitude of 225%, a crack was observed in the upper right corner of the opening. To observe the state of this concrete segment, a small portion of the pvc panel was removed, which exposed a diagonal crack starting at the corner of the opening and terminating at the connector location (see Figure 9b).

When the consecutive test was done (VERTEQ-II 250%), the diagonal crack previously observed opened up and increased in length. Also, a hairline flexural crack was formed on the right corner of the beam (Figure 10). No more additional increases in amplitude for the record were performed and position transducers were disconnected.



Figure 9a — Crack at the upper right corner of the opening after VERTEQII-225%



Figure 9b — Part of OCFS taken off, diagonal crack found after VERTEQII-225%



**Figure 10— Hairline flexural crack at the right corner of the beam
after VERTEQII-250%**

The earthquake records Llolelo (1985) with an amplitude of 0.60g, and El Centro (1940) with an amplitude of 0.80g were applied to specimen. To observe the crack width under the pvc, some of the material was partially removed from all four corners of the opening. These existing cracks opened further and additional hairline flexural cracks formed along the span of the beam.

The final tests done on the specimen included four sequences of VERTEQ-II records with 30 second waiting time between records. Incorporated within these sequences were: two VERTEQ-II 100%, three VERTEQ-II 200%, three VERTEQ-II 225% and three VERTEQ-II 250%. These tests produced no additional cracks; however, existing cracks became wider and longer. No additional dynamic tests were performed (Figure 11).

At the end of testing, specimen 2 showed a minimal amount of diagonal cracks at the corners of the opening and significant flexural cracks at the ends of the beam. All flexural cracks observed along the span of the beam coincided with the location of the center line of each OCFS panel (see Figure 12).

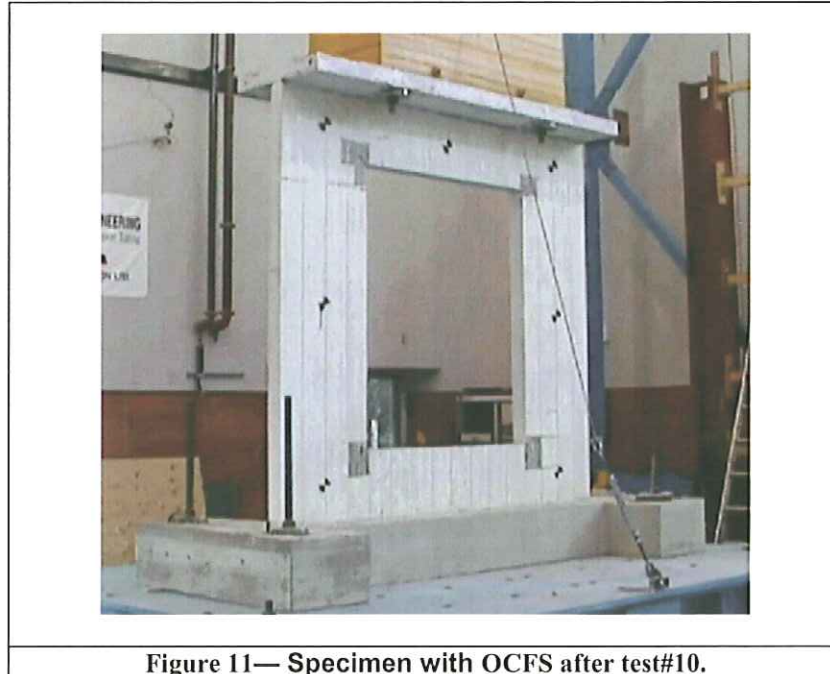


Figure 11— Specimen with OCFS after test#10.

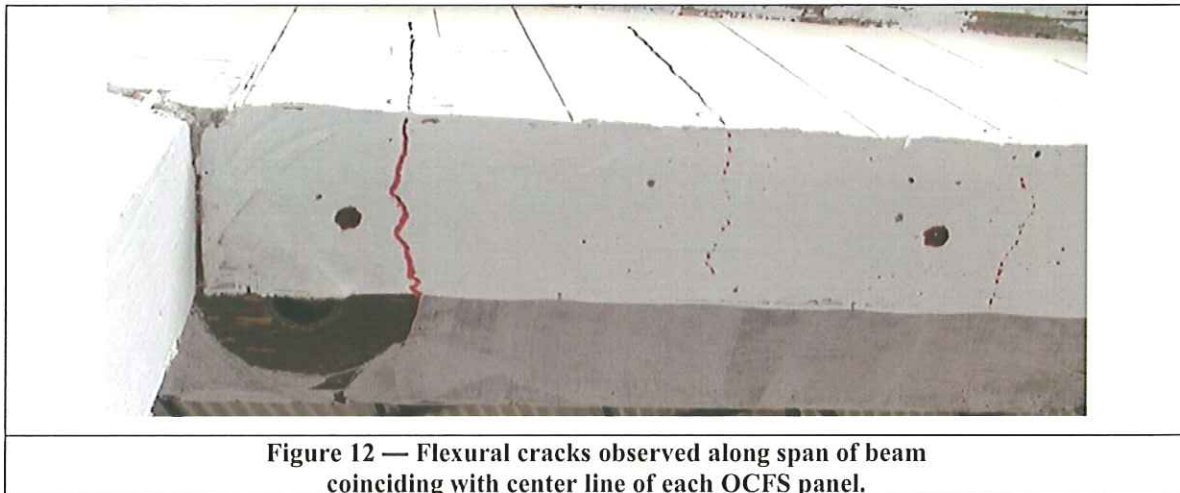


Figure 12 — Flexural cracks observed along span of beam coinciding with center line of each OCFS panel.

Comparison of test results for both specimens

For the benchmark test specimen, hairline flexural cracks were observed at the mid-span of the beam due to the applied surcharge weight. For the test specimen with the OCFS, no flexural cracks were observed due to the applied weight.

After the incremental dynamic loading, the benchmark specimen showed severe flexural cracks and eventually spalling at the lower end of the left column. For the specimen with the OCFS, no flexural cracks were found at the columns after partially removing a panel from the surface at the same location (see Figure 13b).

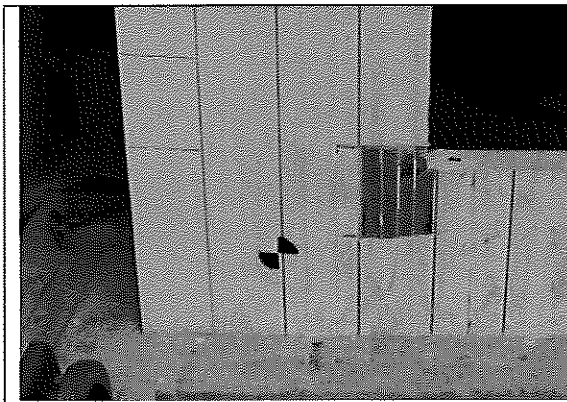


Figure 13a — Lower Left Corner of Specimen 2, where collapse originated in Specimen 1.



Figure 13b — Left side of column of Specimen 2, no cracks found

Flexural cracks formed along the span of the beam for both specimens although, the location of cracks significantly differed. For specimen 1, the flexural cracks coincided with the location of the vertical reinforcement. For specimen 2, the flexural cracks mostly coincided with the location of the center line of each OCFS panel. The widths of the cracks in the beam of specimen 2 were smaller than the corresponding cracks observed in specimen 1.

Figure 14a shows the variation of the inertial force versus the displacement for both specimens during the fifth dynamic loading, VERTEQII 200%. The load deformation plot for specimen 2 shows a higher stiffness than specimen 1, which relates to the difference in cracking observed for both specimens at this stage of testing. After increasing the dynamic load to VERTEQII 250%, the load deformation plot for specimen 2 showed a similar stiffness to specimen 1 at VERTEQII 200% (see Figure 14b). This

suggests that cracks were formed within the cross section of the specimen with the OCFS, but at higher loads. Little energy dissipation was observed for both specimens.

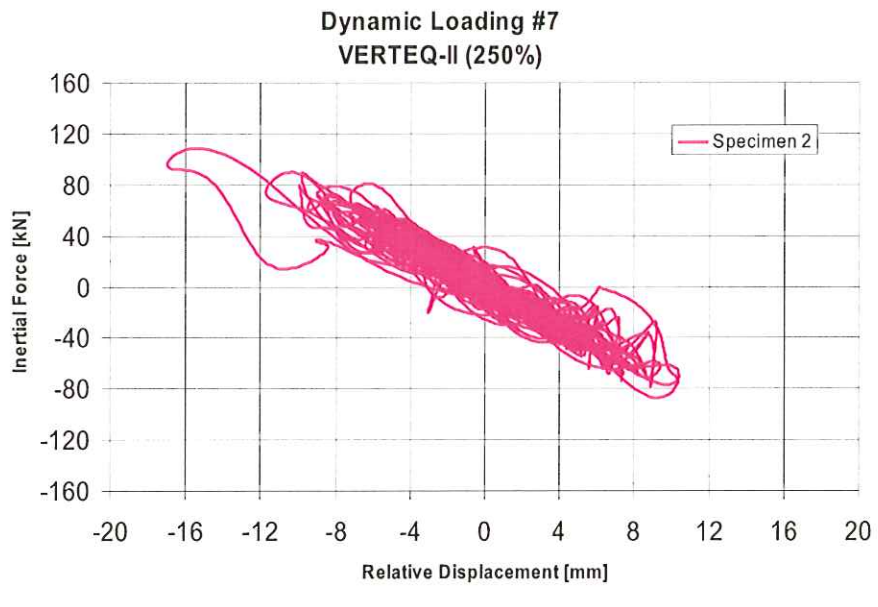
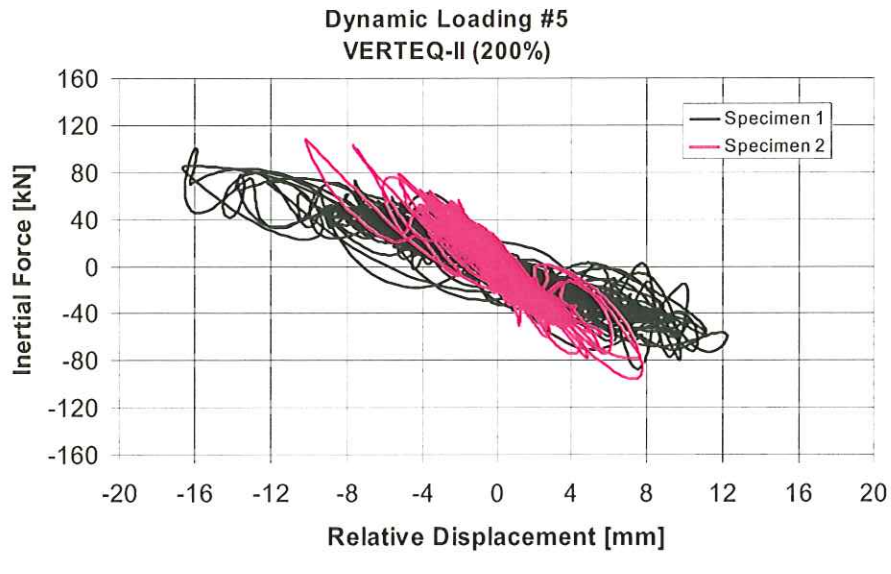


Figure 14 —Inertial Force vs. Displacement for
 a) dynamic Load #5 VERTEQII 200%
 b) dynamic Load #7 VERTEQII 250%

Conclusions

1. For the specimen with the OCFS, no flexural cracks were found in the columns after partially removing the material.
2. Flexural cracks formed along the span of beam for both specimens; however, the location of cracks significantly differed.
3. The width of the cracks on the beam of the specimen with the OCFS were smaller than the corresponding cracks on the benchmark specimen.
4. The loss in stiffness for the specimen with the OCFS after testing for a 250% amplitude VERTEQII , was similar to that of the benchmark specimen after testing for 200% VERTEQII.
5. From the dynamic loading tests performed, it was shown that the OCFS protects a reinforced concrete structure against spalling during a severe earthquake.
6. The OCFS specimen in comparison to the benchmark specimen had a greater lateral load capacity and could resist more cycles of shaking.

RECOMMENDATIONS

Cyclic testing should be performed on different reinforced concrete structures with the OCFS, measuring the strains in the different materials to establish its influence on the displacement and strength capacity of a structure.

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APPENDIX

ELECTRONIC INFORMATION

EERF OCTAFORM TESTS DVD #1.....

Construction Details and Drawings

Instrumentation Data during Tests

Photos of Shake Table Tests

Videos of Shake Table Tests

EERF Report

EERF OCTAFORM TESTS DVD #2.....

HIGH SPEED CAMERA VIDEO AVI FILES (200 Frames Per Second)

APRIL 10:

Test 5: VERTEQII 200%

Test 6: Llolle

Test 7: El Centro

Test 8 Sequence of 2 VERTEQII 100%

Test 9 Sequence of 3 VERTEQII 200%

APRIL 16:

Test 2 VERTEQII 200%

Test 3 VERTEQII 225%

Test 4 VERTEQII 250%

Test 5 Llolle

Test 8 Sequence of 3 VERTEQII 200%

Test 9 Sequence of 3 VERTEQII 225%

Test10 Sequence of 3 VERTEQII 225%