RESEARCH HIGHLIGHT

December 2003 Technical Series 03-127

Static and Dynamic Earthquake Testing of Rainscreen Stucco Systems for B.C. Residential Wood-Frame Construction

INTRODUCTION

While British Columbia does not face the same high frequency of large, damage-inflicting earthquakes as does California, the largest subduction earthquake predicted for North America will affect the south end of Vancouver Island and the Lower Mainland. Such an earthquake (caused by the collision and underthrusting of tectonic plates) has a high probability of occurrence this century. Without substantial improvements to the earthquake preparedness of British Columbia's housing infrastructure, the consequences of a large earthquake could be devastating.

Research has shown that non-structural building components, such as stucco cladding and drywall, can have a major influence on earthquake performance. In response to the moisture penetration problems experienced in contemporary residential construction in southwestern British Columbia, the adoption of "rainscreen" stucco wall systems, whereby an air cavity is incorporated to provide a capillary break and to allow drainage of bulk water immediately behind the cladding, thereby substantially reducing moisture penetration, is mandated in some jurisdictions. However, the earthquake performance of this "rainscreen" stucco system is unknown.

The primary objective of this research was to undertake a comparative evaluation of rainscreen and non-rainscreen stucco systems to determine if there is any significant change in earthquake performance through the introduction of the rainscreen cavity. The secondary objectives of this research were to assess the ability of rainscreen stucco to withstand large earthquakes and to develop refinements to the design of rainscreen stucco systems for improved earthquake performance.

RESEARCH PROGRAM

The research program consisted of two parts: component static testing and full scale dynamic testing. The rate of loading for the static tests was slow compared with that for the dynamic tests. All testing, both static and dynamic, was performed in the Structures Laboratory at the University of British Columbia.

Component Static Testing

The purpose of the static tests was to determine the variation in shear strength with lateral or in-plane deformation for stucco systems of different construction. The results of these static tests were used to model stucco behaviour in the analytical software developed to predict earthquake damage.

A total of 18 panels were tested: three non-rainscreen stucco panels and 15 rainscreen stucco panels. The wood-frame test panels were each 1,219 mm long x 2,438 mm high (4 ft. x 8 ft.) consisting of 38 x 89 (2 x 4 in., nominal) wood studs at 400 mm (16 in.) centres. Vertical strips of 89 mm (3.5 in.) wide and 11 mm (0.4 in.) thick OSB (oriented strand board) sheathing was nailed to each vertical stud; the OSB sheathing was not continuous to allow the stucco strength data to be generated directly. Vertical strapping, aligned with each vertical stud, was nailed to the OSB sheathing for the rainscreen stucco systems; the strapping was omitted for the non-rainscreen stucco. The stucco mix was in accordance with the 1998 British Columbia Building Code. The earthquake resistance was evaluated for the following parameters:

- type of strapping material (SPF (spruce, pine, fir) or plywood)
- type of strapping nails (roofing or common)
- length of strapping nails—38, 50 or 64 mm (1.5, 2 or 2.5 in.)
- type of lath fastener (roofing nails, electroplated staples or stainless steel staples)
- lath fastener length—38 or 50 mm (1.5 or 2 in.)

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While lath type also varied (welded wire mesh, expanded metal mesh with building paper, or heavy duty K-lath with backing paper), the limited number of lath types tested did not constitute a comprehensive assessment.

The panels were installed vertically in a test rig with hold-downs at the bottom, such that only lateral (in-plane) movement was permitted (see Figure 1). An actuator and load cell subjected each panel to pre-determined lateral displacements at the top of the panel. Test cycles were conducted in pairs, one in each direction; the lateral movement of each test cycle pair was 6, 12, 24, 48, 96, 144 and 192 mm (1/4, 1/2, 1, 2, 4, 6 and 8 inch, nominal), representing approximate drifts of 0.25, 0.5, 1, 2, 4, 6 and 8 per cent, respectively. Testing was stopped when the test specimen had effectively failed or the last cycle (maximum drift) was applied. Recorded test data included resistance at the top of the panel, lateral deformation or drift at the top of the panel, and uplift at each hold-down. The primary test output was the hysteretic static force versus deformation curves for each test cycle for each panels. This parametric test data is crucial for the determination of strength, ductility and earthquake damage estimates. The parametric data from the static tests was used to predict earthquake damage (drift) for the two dynamic tests.

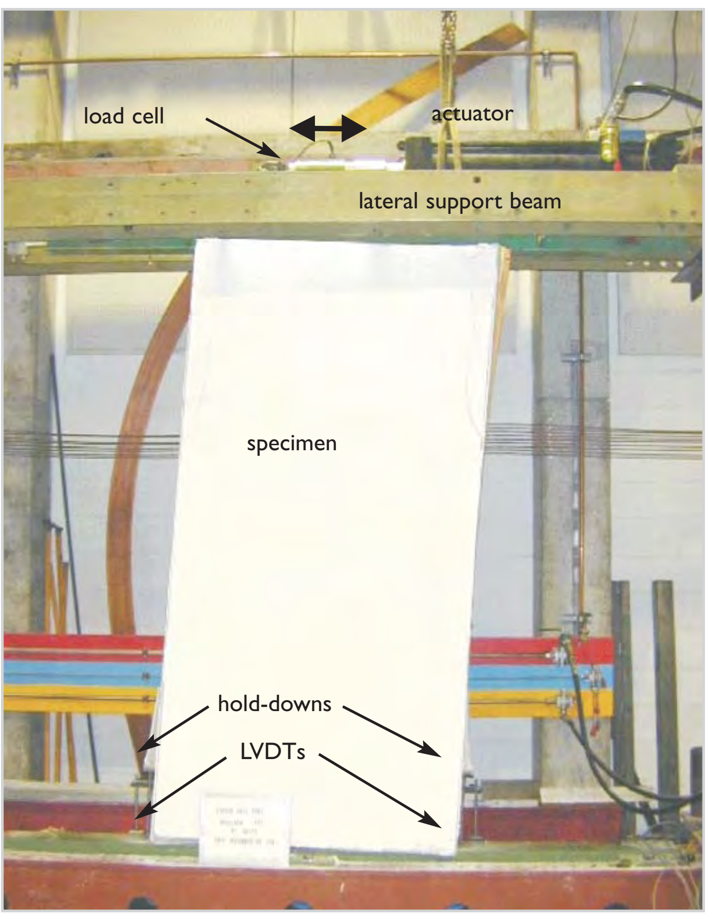

Figure 1 Photograph of Panel Subjected to the Static Test

A separate strapping test was conducted on an additional frame, free of building paper, lath and stucco. The purpose of this separate test was to examine the effect of different combinations of strapping and lath fasteners on possible splitting of the two types of strapping used.

Full Scale Dynamic Testing

The dynamic tests were conducted to investigate and compare the behaviour of a full-scale building, with non-rainscreen stucco and with rainscreen stucco, subjected to the ground motions of past recorded earthquakes. Three earthquakes were simulated (the modified Nahanni earthquake, the Landers earthquake and the Kobe JMA earthquake), each representing a gradual progression in severity of ground motion shaking and different durations of shaking.

The houses tested were 93 m^2 (Approximately1,000 sq. ft.) in area [7.6 m (25 ft.) in the direction of shaking by 6.1 m (20 ft.)] of typical wood-frame construction. The houses featured all materials and components that could have an influence on the seismic performance, including exterior cladding (stucco), drywall, interior partitions, doors and windows. Floor and roof loads were simulated with concrete blocks attached to the relevant surfaces. The stucco system for the non-rainscreen test utilized 38-mm (1.5 in.) welded wire mesh held with 38-mm (1.5 in.) staples. The stucco system for the rainscreen test utilized a heavy-duty K-lath secured with 50-mm (2 in.) staples and SPF strapping secured with 64-mm (2.5 in.) roofing nails.

The test house (see Figure 2) was supported on a horizontal steel frame, which acted as the foundation for the house. The steel frame was supported on low- friction rollers that permitted uni-directional motion.

The steel frame was driven by a high capacity actuator mounted on the plan centreline of the frame to simulate the ground motion of actual earthquakes by regulating the shake table actuator force (in kN), steel frame displacement (in cm) and acceleration (in g's). Instrumentation to record the movement of the house was mounted on a steel column adjacent to the house. The primary data recorded for each test included:

- peak values of absolute acceleration in the direction of movement at the roof level, 2nd floor level and base level
- relative displacements and drift for each wall at the roof and 2nd floor levels in comparison to the base level
- anchor rod loads at the 2nd floor and base levels

The primary test output was the drift time history of the first and second storeys. These drift time histories permit a comparative and absolute assessment of the earthquake performance.

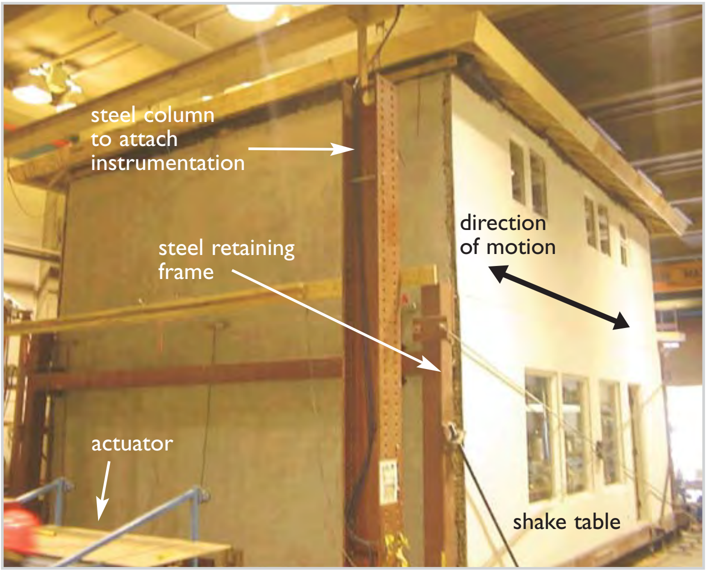

Figure 2 Photograph of the Test House for the Dynamic Tests

RESULTS

Component Static Testing

With respect to the lath, the earthquake performance of panels with staple lath fasteners was found to be superior to that of panels with nail fasteners. Panels with longer staples—50 mm (2 in.) exhibited substantially better strength than panels with shorter staples—38 mm (1.5 in.). In summary, the use of staples is recommended over nails and there should be a minimum penetration into the stud of 25 mm (1 in.), or total penetration of sheathing and minimum penetration of 16 mm (5/8 in.) into the stud. Staples should be installed with the staple legs at diagonally opposite sides of the intersection of the horizontal and vertical wires of the welded wire mesh. If the vertical wire of the lath is not centered on the stud to allow staple penetration into the stud, the staple should be installed vertically with the staple legs on either side of the horizontal wire. Maximum staple spacing for studs at 400 mm (16 inches) spacing is 150 mm (6 in) vertically and 400 mm (16 in) horizontally (—600 mm (24 in) stud spacing was not studied).

With respect to the strapping, pressure-treated plywood strapping was found to have better ductility than pressure-treated SPF strapping and showed less strength degradation at higher drift levels. The strength performance of the test panels with roofing nails was almost 40 per cent better than that with common nails. Short strapping nails—38 mm (1.5 in.) precipitated brittle failure of the cladding. Long strapping nails—64 mm (2.5 in.) gave better performance. In summary, the preferred strapping is 19 x 75 mm (3/4 in. x 3.0 in.) plywood secured to the sheathing and studs with 64 mm (2.5 in.) hot-dipped galvanized roofing nails at no more than 300-mm (12 in.) spacing.

Full Scale Dynamic Testing

Both houses performed very well, with neither house sustaining significant earthquake damage. The only evidence of damage was small cracks emanating from the re-entrant window and door corners. The performance of both tests was comparable, though the rainscreen house was stiffer than the non-rainscreen house due to the influence of the strapping. The dynamic tests were especially valuable in refining and verifying the reliability of the earthquake damage estimation software that has been developed as part of another research project.

IMPLICATIONS FOR THE HOUSING INDUSTRY

The research project demonstrated that the performance of rainscreen and non-rainscreen stucco is comparable, and that either system has the potential to effectively eliminate major structural earthquake damage in residential wood-frame buildings (single family and multi-unit construction). However, refinements to current stucco construction practice will make a major contribution to capitalizing on this impressive mitigation potential. In particular, the use of 50-mm (2 in.) staples as lath fasteners should replace the current practice of nails, and plywood strapping secured with roofing nails should be used in rainscreen stucco construction.

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Research Report: *Static and Dynamic Earthquake Testing of Rainscreen Stucco Systems for B.C. Residential Wood-Frame Construction*

Research Consultants: TBG Seismic Consultants Ltd. and Department of Civil Engineering, University of British Columbia

CMHC undertook this project in partnership with the Homeowner Protection Office and the British Columbia Housing Management Commission.

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Under Part IX of the *National Housing Act*, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research.

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