Chapter 7 Summary and Conclusions

7.1 Summary and Conclusions

Five long shear wall configurations containing various opening schemes and anchored at the extreme ends of the wall were investigated. Each shear wall configuration was examined under monotonic and cyclic displacements and the results have been discussed.

Observations and conclusions obtained from the shear wall tests are as follows:

1. The perforated shear wall method, based on the work of Sugiyama and Matsumoto (1994), predicted conservative capacities when applied to both monotonic and cyclic capacity. Predictions became overly conservative as the area of openings increased. The perforated shear wall method was also applied using the ultimate design capacity as the reference capacity, and, again, conservative predictions were made. Ultimate design capacity was used because the actual capacity is often not known in design applications. Monotonic shear wall test results further verify the perforated shear wall method as a method of conservative prediction for shear walls with openings and tie-down anchorage at the ends of the wall.
2. Full height plywood sheathing panels were observed to perform in a racking manner and plywood panels above and below openings were observed to perform as a rigid body.
3. Gypsum wallboard was additive during elastic behavior of the shear wall, and was observed to resist lateral load at higher interstory drifts during monotonic tests than cyclic tests. Gypsum nailing tore a path through the gypsum wallboard, and can only resist shear at high interstory drifts once. Gypsum was providing no shear resistance near capacity during cyclic tests.
4. Out-of-plane buckling of plywood sheathing was observed only in monotonic tests when full height sheathing panels were adjacent to sheathing above or below openings. Out-of plane buckling was only observed in Walls B and C for one plywood panel.
5. Tie-down anchorage did not fail during any of the shear wall tests. Slip of the tie-down anchor relative to the end studs was negligible during monotonic and cyclic tests.
6. Failure of the plywood sheathing nailing attached to the bottom and top plate was the predominant cause of failure. For monotonic tests, pull-through of the plywood nails was observed. For cyclic tests, fatigue of the plywood nails was the main cause of failure. Failure of the nails occurred first in the corners and progressively unzipped down the top or bottom plate until the panel separated from the wall. At this point, the load was redistributed to the remaining panels. Failure of the wall was observed shortly thereafter.
7. Anchor bolts, attaching the bottom plate to the foundation, were placed every 2 ft. (0.6 m). For walls with door openings, there was a minimum distance of 12 in.

(305 mm) between the anchor bolt and the edge of the door opening. Upward bending of the bottom plate was observed during the tests. Tie-down anchorage would prevent bending of the bottom plate at openings.

8. As mentioned in (2), full height sheathing was observed to rack and cut sheathing acted as a rigid body. Due to the rigidity of the cut panels, the double studs adjacent to panels below openings were observed to bend at the corner of the rigid sheathing panels. Bending of the double studs adjacent to window openings was observed in Walls C and D (at 32 in. (0.8 m) from the bottom of the shear wall).
9. Uplift of the double end studs was minimized due to the tie-down anchors. Uplift that occurred was due to bending of the tie-down anchors and not due to slip between the tie-down anchor and the end studs. Uplift never exceeded 0.18 in. (5 mm) at wall capacity during monotonic and cyclic tests.
10. Although no direct measurement was taken, uplift of studs adjacent to door openings was observed to be as high as 2 in. (51 mm) after capacity had been reached. Sheathing nails attaching the plywood to the bottom plate were observed to pull out of the framing, allowing more rotation of the panel
11. Monotonic data did not give any information regarding cyclic performance. Trends found indicate that walls with less stiffness have cyclic capacity closer to monotonic capacity than walls with higher stiffness. The ratio of cyclic capacity to monotonic capacity was greater than 0.9 for Walls C, D and E and less than 0.9 for Walls A and B.
12. Monotonic load-drift curves are longer and had greater load magnitude than cyclic load-envelope curves. Average interstory drift at capacity of the five wall configurations was 2.1 in. (53 mm) for monotonic tests and 1.2 in. (30 mm) for cyclic tests. Average interstory drift at failure of the five wall configurations was 4.5 in. (114 mm) for monotonic tests and 2.0 in. (51 mm) for cyclic tests. Fatigue failure of the plywood sheathing nails was the predominant reason for the low interstory drift at failure during cyclic loading.
13. Ductility data has been presented and found not to be a reliable indicator of performance. Ductility must be viewed in relation to stiffness, yield resistance, and capacity to provide an overall evaluation of performance.
14. Monotonic and cyclic stiffness have been presented. As expected, walls with more sheathing nails had higher elastic stiffness. Catastrophic failure of walls with high stiffness was observed compared to walls with lower stiffness.
15. The natural log method of capacity prediction was developed based on trends found in this thesis and found to give conservative predictions with similar reserve capacities for the five wall configurations examined. Similar trends are expected to be found for a larger set of data. Although beyond the scope of this thesis, the natural log method should be applied to existing monotonic data to determine if an equation can be found that gives conservative predictions for a larger variety of shear wall configurations.

7.2 Future Research

Shear wall tests examining the effect of tie-down anchorage on the five shear wall configurations are currently being conducted at Virginia Polytechnic Institute and State University. The five shear wall configurations are being examined with no tie-down anchorage and with tie-down anchorage adjacent to openings.

Continued testing of shear walls with openings under cyclic loading is needed to better understand and better design shear walls for earthquakes. Tables of nail schedules should be determined for earthquake design based on actual cyclic tests, rather than monotonic tests. Further cyclic testing of wooden shear walls and diaphragms will allow efficient utilization of wood that can safely handle earthquake loading.

All cyclic performance data determined in this thesis was conducted on shear walls with no prior cyclic 'history'. An investigation into cyclic performance of shear walls with openings that has undergone previous repetitive cyclic displacements will offer valuable long-term performance data since timber structures in high seismic zones are likely to experience multiple seismic events.

Based on promising results based on the capacity data determined in this thesis, an extensive investigation of the applicability of the natural log method should be done. A design methodology that conservatively predicts capacity, with similar reserve strength, is needed.