Appendix A: Details of Quasi-Static Cyclic Testing Protocols

A.1 Introduction

In addition to the monotonic strength and stiffness test data needed for diaphragm design of buildings constructed of timber frame and SIPs, current building codes also lack information regarding cyclic performance of these structures that would allow designers to assess their resistance to seismic ground accelerations experienced during earthquakes. It was therefore decided to subject different configurations of the roof assemblies, as described in Chapter 3, to series of low level cyclic tests in order to assess behavior of timber frame and SIP roof systems under seismic loads and calculate seismic design parameters for these assemblies, as discussed in Chapter 4. Cyclic stiffness tests were conducted on all assemblies utilizing displacements that would not damage the assemblies prior to failure tests. Assembly 2 was subject to a cyclic failure regime, but only after a monotonic failure test had been conducted, as explained in Chapter 3, and this test was terminated due to excessive bending of the steel member attached to the hydraulic actuator and the center rafter.

A.2 Cyclic Stiffness Loading Protocol Utilizing Basic Loading History

The Basic Loading History for quasi-static cyclic testing as defined by Krawinkler et al. (2001) is presented below as a list of deformations in Table A.1. Displacements utilized for cyclic stiffness testing were based on this waveform, the only difference being that after the final primary cycle and two trailing cycles following it, the displacement returns to zero and the test ends, rather that continuing on to increased deformations. Reference deformation, Δ, for cyclic stiffness tests was considered the maximum displacement the assembly could be subjected to without causing degradation to the system. Derivation of Δ was discussed in Chapter 3 and was initially selected as 0.1 in. (2.5 mm) upon inspection of load versus deflection plots, where a slight decrease in incremental load for incremental displacement was observed, indicating that further displacement would likely have damaged the specimens. Cycle time, or time elapsed between two positive (or negative) peaks was 12 seconds in order to maintain consistency

Table A.1. Loading cycle sequence of basic loading history for low level cyclic stiffness testing.

Number of Cycles	Type of Cycle	Displacement
6	initiation	0.05Δ
1	primary	0.075Δ
6	trailing	0.056Δ
1	primary	0.1Δ
6	trailing	0.075Δ
1	primary	0.2Δ
3	trailing	0.15Δ
1	primary	0.3Δ
3	trailing	0.225Δ
1	primary	0.4Δ
2	trailing	0.3Δ
1	primary	0.7Δ
2	trailing	0.525Δ
1	primary	1.0Δ
2	trailing	0.75Δ
For tests to failure, the remainder of the test consists of a sequence of one primary cycle followed by two trailing cycles, where the amplitude of each primary cycle is increased by 0.5Δ and each trailing cycle pair is increased by 0.375Δ.		

with previously conducted cyclic tests and to avoid any inertia effects of the moving assembly. Table A.2 and Figure A.1 provide actual waveform displacement and time data utilized for cyclic stiffness tests with 12 second cycle time and maximum deformation of 0.1 in. (2.5 mm). All construction configurations were subject to the cyclic protocol illustrated in Figure A.1, as discussed in Chapter 3. Displacements and corresponding elapsed time based on the Basic Loading History (Krawinkler et al., 2001) were easily calculated utilizing an Excel spreadsheet created by William P. Jacobs V, a fellow graduate student in Civil Engineering at Virginia Tech.

During exploratory testing conducted on Assembly 2, as discussed in Chapter 4, it was decided to subject the completed panel to a waveform with a maximum displacement of 0.25 in. (6.4 mm) and a cycle time of 12 seconds to determine if this would damage the specimen. Displacement and time data for this waveform are presented in Table A.3 and Figure A.2. No damage was observed and therefore the bare timber frames and fully constructed assemblies were subjected to this cyclic regime for the remaining assemblies, as described in Chapter 3.

A.3 Cyclic Failure Loading Protocol Utilizing Basic Loading History

The only test conducted utilizing the Basic Loading History for quasi-static cyclic testing as defined by Krawinkler et al. (2001) was conducted on Assembly 2 after the previous monotonic failure test was terminated due to bending of the steel channel attached to the hydraulic actuator and center rafter, as discussed in Chapter 4. Data from the monotonic failure test on Assembly 1 provided monotonic deformation, Δ_m, of 1.703 in. (43 mm). Monotonic deformation, Δ_m, was defined as displacement at which applied load (during static testing) initially dropped below 80% of maximum applied load. Krawinkler et al. (2001) recommended using 60% of Δ_m for determination of reference deformation Δ, which resulted in $\Delta = 0.6(\Delta_m)$, or 1.02 in. (26 mm). Displacement and time data for this failure waveform are presented in Table A.4 and Figure A.3. The most significant difference between the failure protocol and the stiffness protocols previously described is that when going to failure, the amplitudes increased beyond the primary cycle with reference deformation Δ and the two trailing cycles. Displacement for each additional primary cycle was increased by 0.5Δ and the following two trailing cycles

Table A.2. Loading cycle sequence for low level cyclic stiffness testing with maximum displacement of 0.1 in. (2.5 mm).

Number of Cycles	Type of Cycle	Displacement
6	initiation	0.005 in. (0.13 mm)
1	primary	0.008 in. (0.20 mm)
6	trailing	0.006 in. (0.14 mm)
1	primary	0.01 in. (0.25 mm)
6	trailing	0.008 in. (0.20 mm)
1	primary	0.02 in. (0.51 mm)
3	trailing	0.015 in. (0.38 mm)
1	primary	0.03 in. (0.76 mm)
3	trailing	0.023 in. (0.58 mm)
1	primary	0.04 in. (1.02 mm)
2	trailing	0.03 in. (0.76 mm)
1	primary	0.07 in. (1.78 mm)
2	trailing	0.053 in. (1.35 mm)
1	primary	0.1 in. (2.5 mm)
2	trailing	0.075 in. (1.91 mm)

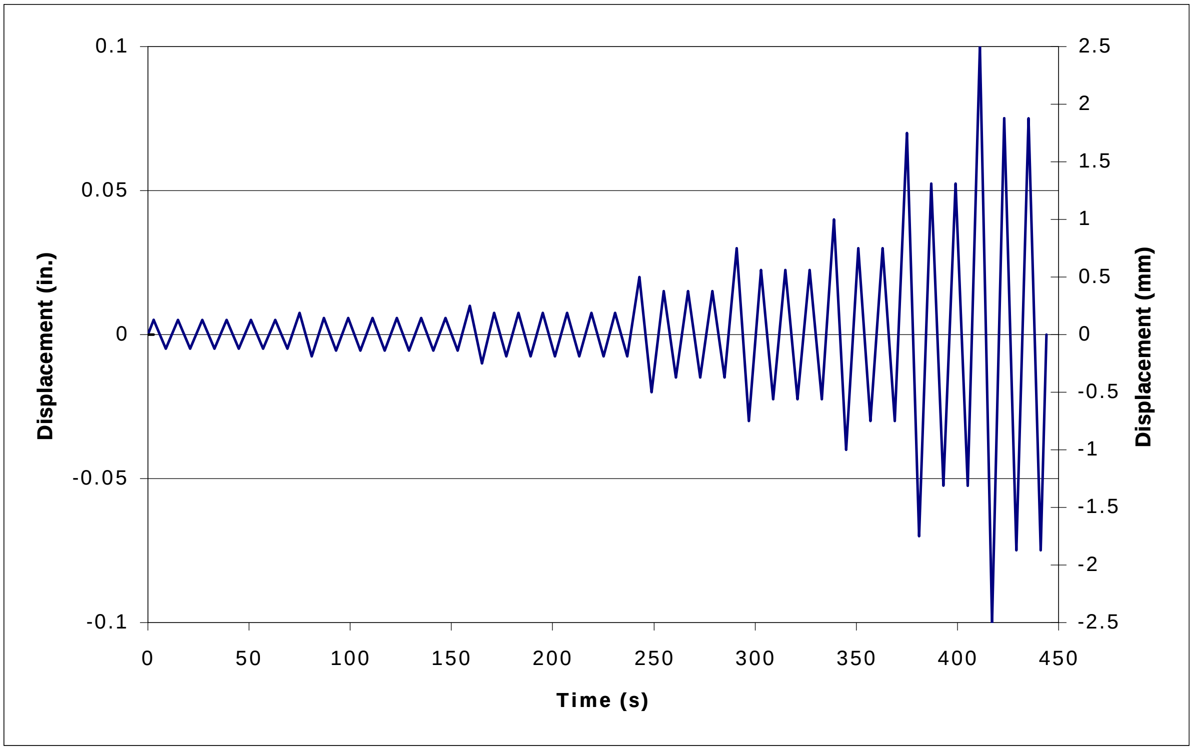

Figure A.1. Loading sequence utilized for low level cyclic stiffness testing with maximum displacement of 0.1 in. (2.5 mm).

Table A.3. Loading cycle sequence for low level cyclic stiffness testing with maximum displacement of 0.25 in. (6.4 mm).

Number of Cycles	Type of Cycle	Displacement
6	initiation	0.013 in. (0.32 mm)
1	primary	0.019 in. (0.48 mm)
6	trailing	0.014 in. (0.36 mm)
1	primary	0.025 in. (0.64 mm)
6	trailing	0.019 in. (0.48 mm)
1	primary	0.05 in. (1.27 mm)
3	trailing	0.038 in. (0.95 mm)
1	primary	0.075 in. (1.91 mm)
3	trailing	0.056 in. (1.43 mm)
1	primary	0.1 in. (2.54 mm)
2	trailing	0.075 in. (1.91 mm)
1	primary	0.18 in. (4.45 mm)
2	trailing	0.13 in. (3.33 mm)
1	primary	0.25 in. (6.35 mm)
2	trailing	0.19 in. (4.76 mm)

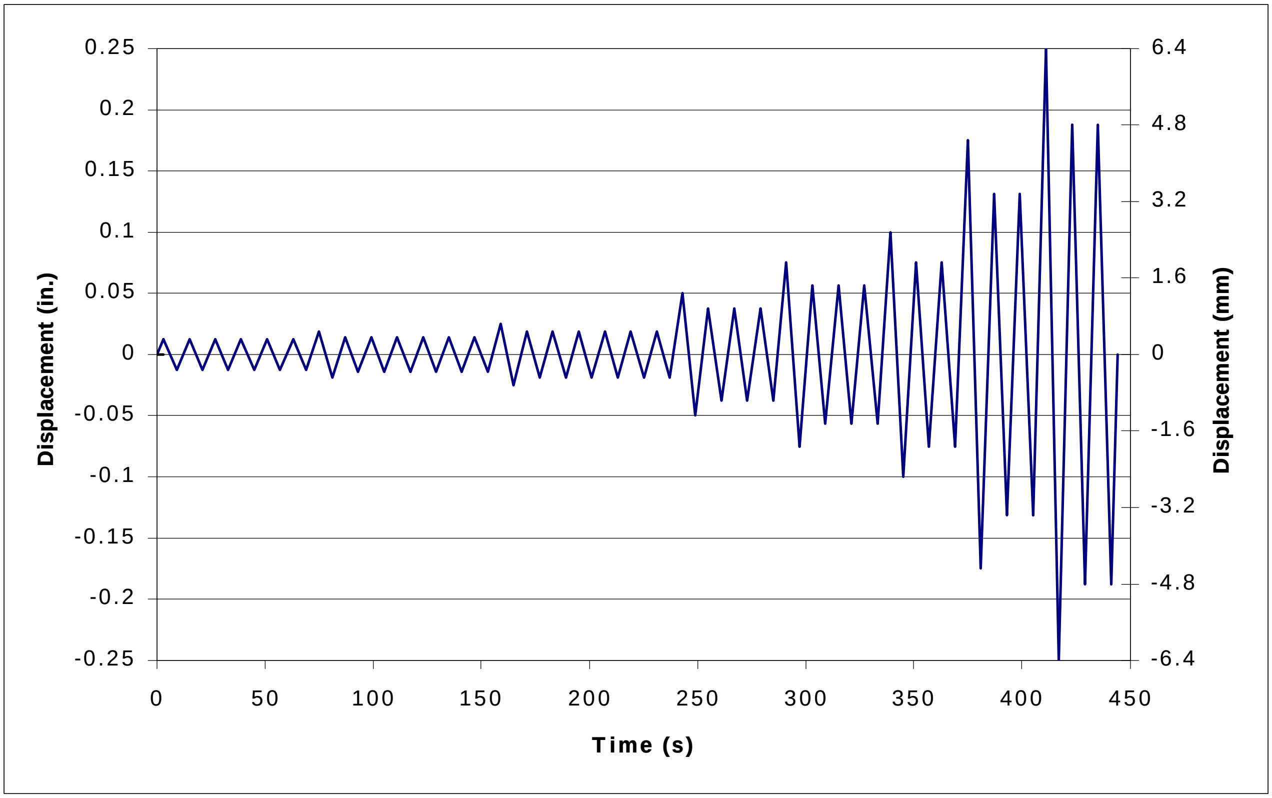

Figure A.2. Loading sequence utilized for low level cyclic stiffness testing with maximum displacement of 0.25 in. (6.4 mm).

Table A.4. Loading sequence utilized for cyclic failure test conducted on Assembly 2 with utilizing reference deformation 1.02 in. (26 mm) obtained from monotonic failure test on Assembly 1.

Number of Cycles	Type of Cycle	Displacement
6	initiation	0.051 in. (1.30mm)
1	primary	0.077 in. (1.94 mm)
6	trailing	0.057 in. (1.45 mm)
1	primary	0.10 in. (2.59 mm)
6	trailing	0.077 in. (1.94 mm)
1	primary	0.20 in. (5.18 mm)
3	trailing	0.15in. (3.89 mm)
1	primary	0. 31 in. (7.77 mm)
3	trailing	0.23 in. (5.83 mm)
1	primary	0.41 in. (10.4 mm)
2	trailing	0. 31 in. (7.77 mm)
1	primary	0.71 in. (18.1 mm)
2	trailing	0.54 in. (13.6 mm)
1	primary	1.02 in. (25.9 mm)
2	trailing	0.77 in. (19.4 mm)
1	primary	1.53 in. (38.9 mm)
2	trailing	1.15 in. (29.2 mm)
1	primary	2.04 in. (51.8 mm)
2	trailing	1.53 in. (38.9 mm)
1	primary	2.55 in. (64.8 mm)
2	trailing	1.91 in. (48.6 mm)
1	primary	3.06 in. (7.77 mm)
2	trailing	2.30 in. (58.3 mm)

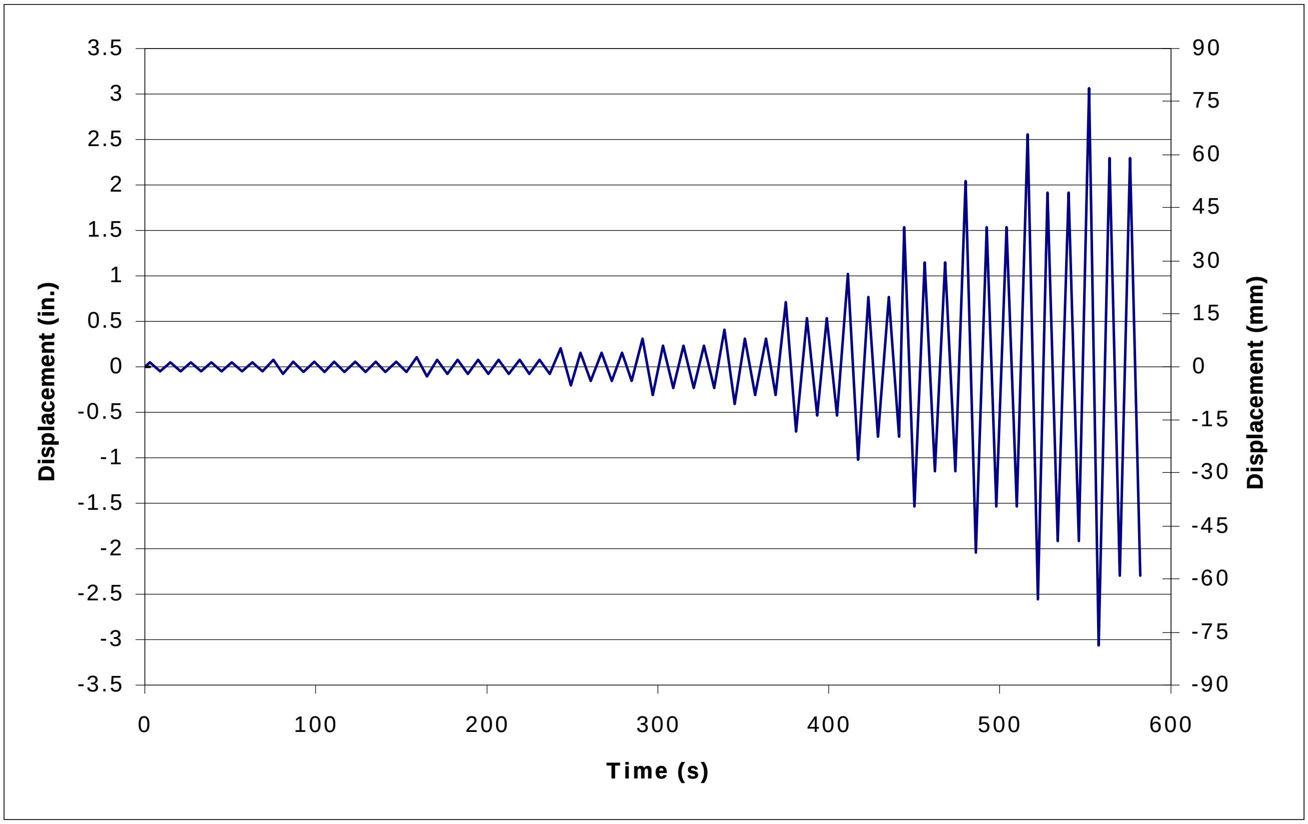

Figure A.3. Loading sequence utilized for cyclic failure test conducted on Assembly 2 with utilizing reference deformation 1.02 in. (26 mm) obtained from monotonic failure test on Assembly 1.

were increased by 0.375Δ. It was assumed that four additional primary cycles and subsequent trailing cycles would have induced failure in the assembly. Cyclic failure testing of Assembly 2 was terminated before the entire protocol was conducted due to continued bending of the steel channel.

Information and data obtained from quasi-static cyclic testing was used to calculate cyclic behavior parameters as discussed in Chapter 4. In Chapter 5 these parameters are utilized to perform an example seismic design in a high level seismic zone in order to verify the ability of the SIP and timber frame roof assemblies to resistearthquake induced lateral loads.