Anchorage of Woodframe Buildings: Laboratory Testing Report

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Summary

Testing of anchorage connections was conducted under Task 1.4.1.1 Anchorage of Woodframe Buildings as a part of the CUREE-Caltech Woodframe Project. The purpose of the testing was to improve the understanding of the seismic performance of sill plate-to-foundation anchorage connections.

A series of laboratory tests of full-scale anchorage connections was performed using two different test setups. The tests were designed to evaluate a number of variables related to the sill plate anchorage configurations. For purposes of evaluating test variables and performance levels, test results were placed into four groups. The setup for the first two groups of tests used four-foot long plywood shearwalls attached to a simulated concrete foundation using anchor bolts or power-driven pins. These specimens were loaded horizontally 12-inches above the sill plate to minimize the effects of overturning. The setup for the second two groups of tests used a traditional 8-foot by 8-foot shearwall assembly that was loaded horizontally at the top of the wall. The first three groups of tests did not include holdown devices and the fourth group included holdowns to resist uplift.

Cyclic loads were applied to the specimens for each test using a force-controlled loading protocol that was modified slightly from that recommended by Task 1.3.2 Testing Protocols, a component of the CUREE-Caltech Woodframe Project. Target ultimate loads were obtained based on monotonic loading, as recommended in Task 1.3.2.

The Group 1 tests used the first test setup. These tests varied the sill plate width and thickness, the sill plate species, the anchor bolt size and type of washer, and the amount of dead load on the wall. Group 2 tests were similar to Group 1 tests, except that power-driven fasteners were used to attach the sills to the foundation. Even though the test setup was designed to minimize overturning forces, overturning due to the eccentrically applied horizontal load produced uplift of the ends of the sill plate. In general, the 3-inch nominal sill plates and those with heavier plate washers were able to undergo more loading cycles and achieve higher ultimate forces. Walls with larger applied dead loads also resisted higher forces due to net reduced uplift of the ends of
the sill. The Group 2 tests failed by pullout of the power-driven pins at loads that were about one-half of those of the walls with anchor bolts.

The Group 3 tests used the second test setup. These tests included variations in sill plate width and thickness, anchor bolt washer size, anchor bolt location, and anchor bolt hole size in sill plates. The results indicate that the test specimens generally failed due to splitting of the sills. In general, the 3-inch nominal sill plates and those with heavier plate washers were able to undergo more loading cycles and achieve higher ultimate forces.

The Group 4 tests used the same basic test setup as the Group 3 tests, but with holdowns at the ends of the walls. These tests varied the type of anchor bolt washer and type of holdown, as well as incorporating some special connections such as smooth rods instead of anchor bolts. The results indicate that thickness of the sill plate, the stiffness of the anchor bolt washer, and the stiffness of the holdown influences the performance and ultimate strength of the sill plate assembly.

These tests have confirmed that the wall uplifting causes bending and twisting of the sill plate influencing the behavior of the sill plates of a shearwall assembly. The performance and strength improves for walls that incorporate holdowns, use heavy plate washers for the anchor bolts, have larger applied dead loads, or have sill plates that are 3-inch nominal thickness rather than 2-inch nominal thickness. All of these factors tend to limit the cross-grain bending of the sill plate that occurs due to the eccentricity between the plywood and the anchor bolt.

The results of the tests demonstrate that when the sill plates are allowed to bend and twist, brittle failures will occur at low force levels in the sill plates due to the cross-grain bending. When uplift of the shearwalls is limited by holdowns and or dead loads, sill plate bending is reduced. Sill plate-to-foundation connections of shearwall assemblies that utilize full width plate washers and holdowns do not exhibit brittle sill plate failures. The lateral capacity of the wall is governed by the failure of other components of the shearwall assembly.
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Introduction

This report was prepared as part of the CUREE-Caltech Woodframe Project, which is aimed at developing reliable and economical ways of improving woodframe building performance in earthquakes. The Woodframe Project is divided into five interrelated elements: Testing and Analysis; Field Investigations; Building Codes and Standards; Economic Aspects; and Education and Outreach. This report presents the results from the laboratory testing phase of Task 1.4.1.1: Anchorage of Woodframe Buildings, which is within the Testing and Analysis element.

The main objective of Task 1.4.1.1 is to improve the understanding of the seismic performance of sill plate-to-foundation anchorage connections and thereby to increase the reliability of these critical connections under earthquake loading. The impetus of this research results from brittle failures (longitudinal splitting) of sill plates that have been observed after earthquakes and during laboratory testing. Understanding sill plate mechanics and failure mechanisms are required if more reliable sill-plate-to-foundation anchorage connections are to be developed.

Task 1.4.1.1 is divided into two parts: literature review and laboratory testing. The literature review part of Task 1.4.1.1 is contained in an earlier and separate report. The primary purpose of the literature review was to identify and review variables from previous testing and post-earthquake observations, and to confirm initial test variables that should be considered during the laboratory testing part of this task. For the laboratory testing part of Task 1.4.1.1, different sill-plate-to-foundation anchorage configurations were tested. This report addresses the laboratory testing part of Task 1.4.1.1.
Task Methodology

The approach that was taken to accomplish this task was to first identify potential test variables to be evaluated. Initially the test variables included the following:

- wood species,
- anchor bolt diameter,
- power-driven pins,
- sill plate thickness and width,
- washer size and thickness,
- dead loads,
- bolt location in sill plate,
- oversized bolt holes in sill plate,
- retrofitted sill plate connections,
- foundation material.

A literature review on the subject of sill plate-to-foundation connections was then performed. The purpose of the review was to extract relevant information from earlier research. Information from the literature identified several test variables that appear to influence the performance of sill plate-to-foundation connections. Based on the review of the literature, an initial testing program was developed that focused testing on selected test variables while holding other test variables constant. As the testing progressed, adjustments were made in the testing program based on the results of earlier tests. The test results were evaluated, and the performances of different sill plate-to-foundation assemblies were assessed considering the assemblies’ ability to resist cyclic loads.
Laboratory Tests

Through a series of tests, Wiss, Janney, Elstner Associates, Inc. (WJE) evaluated the performance of sill plate-to-foundation connections using traditional anchor bolts and washers, anchor bolts with square plate washers, and power-driven pins. A variety of sill plate widths and thicknesses were also evaluated through testing. Sill plate-to-foundation connections that minimize sill plate cross-grain bending were developed and tested. Alternative connections included blocking between studs and nailed to the sill plate, and rods extending above the sill plate without nuts and washers. Anchor bolts with oversized holes drilled in the sill plate and retrofitted sill plate-to-foundation connections were also evaluated through testing. A test matrix that summarizes each test is contained in Appendix 1.

Test Apparatus

As a logical transition from previous single shear tests identified in the literature review phase to tests on 8-foot by 8-foot shearwall test specimens, an initial series of tests were performed on shearwall specimens with loads applied horizontally, one foot above the sill plate. The horizontal forces loaded the sill plate’s predominately in shear while minimizing overturning forces. The apparatus for the initial series of tests (Tests 1 through 17) is identified as Test Setup 1, and is described below.

For Test Setup 1, an eight-foot high by four-foot long stud wall was built and mounted onto a simulated concrete foundation. A plywood panel, two-foot high by four-foot long, was nailed to the bottom of the stud wall. Simulated dead loads were applied to the top of the stud wall. Lateral loads were applied horizontally to the shearwall via a steel plate bolted to the plywood and located 12-inches above the sill plate. Two anchor bolts or three power-driven pins were used to connect the sill plate to the foundation. Test Setup 1 is illustrated in Figures 1a and 1b.

For the final series of tests, specimens were 8-foot long by 8-foot high shearwalls with loads applied horizontally at the top of the wall. The apparatus for the final series of tests (Tests 18 through 52) is identified as Test Setup 2, and is described below.

Test Setup 2 was similar to typical shearwall tests. An eight-foot high by eight-foot long stud wall was built and mounted onto a simulated concrete foundation. Plywood panels, eight-foot high by four-foot long, were nailed to the stud wall. Simulated dead loads were applied to the top of the stud wall. Lateral loads were applied to the top of the shearwall via a steel plate bolted through the double top plates of the stud wall. Four anchor bolts were used to connect the sill plate to the foundation. Test Setup 2 is illustrated in Figures 2a and 2b.
Figure 1a:
Test Setup One

Figure 1b:
Test Setup One
Figure 2a: Test Setup Two

- Simulated Concrete Footing
- Steel Plate
- Pin
- Bolts to Double Top Plate
- Tube to Loading Ram, Typical.
The test specimens were loaded horizontally using a double acting hydraulic ram. The hydraulic ram is capable of applying a push and pull load up 20,000 lbs. The hydraulic ram was operated manually using a servo-control valve in a load control position, and was attached to the specimen through a series of steel tubes, pins and plates. The ram was attached to structural steel tubes that were welded to a pin-type connection. The pin-type connection was welded to a steel plate that was bolted to the specimen. Loads from the ram were applied through the pin-type connection that was located at the center of the wall. The pin-type connection applied load to the 1/2-inch thick by 5-inch wide steel plate that was bolted to the specimen. The pin-type connection and plate assembly allowed the wall to rotate and uplift without inducing significant secondary forces or restraints onto the test specimens. The distance from the pinned connection behind the loading ram to the pin-type connection at the center of the wall was maximized in order to minimize secondary uplift forces on the specimen as the specimen rocked.

Dead loads were applied to each specimen by securing steel double channels and lead weights to the wall double top plates. The dead loads were positioned over studs.

The test specimens were designed using the Uniform Building Code (UBC) allowable design loads for 5/8-inch diameter anchor bolts and 3-inch nominal sill plates. A target design load of 1120 pounds per anchor bolt (560 plf) was established. The plywood nailing was 8d common at 3-inches on center, and the plywood was rated Structural 1. The plywood nailing and holdowns were designed to be approximately equal or exceed the target design load. A factor of safety of three was assumed between design loads and ultimate strengths for the wood members and connections. As a result, the ultimate target load was estimated at 1680 plf. The simulated foundation and testing apparatus were designed to be stronger than the ultimate capacity of the shearwall assembly.
**Loading Protocol**

The loading protocol developed for this task was based on Task 1.3.2 *Testing Protocols* of the CUREE-Caltech Woodframe Project. Task 1.3.2 developed testing protocols for deformation controlled quasi-static cyclic testing, force controlled quasi-static cyclic testing and input ground motions for shake table tests. Due to the fact that sill plate-to-foundation connections have limited ductility, the force controlled methodology provided in Task 1.3.2 was adapted for Task 1.4.1.1.

The testing protocol specifies a loading history for the test specimens. For a given test specimen, the loading history is based on a reference force, $Q_0$, which is defined as the maximum force the test specimen is expected to experience in the maximum considered earthquake. Rather than develop a $Q_0$, which is the ultimate strength of an assembly based on monotonic loading, for each test specimen, target $Q_0$ values were developed for tests using Test Setup 1 and for tests using Test Setup 2.

The force controlled test protocols presented in Task 1.3.2 specify primary load cycles followed by trailing load cycles with an initial primary load cycle equal to 0.5 times $Q_0$, see **Figure 3a**. Some assemblies being tested were considered to have a potentially brittle failure and this brittle failure may occur at load levels less than $0.5Q_0$. In order to obtain cyclic loading data on assemblies that have a low ultimate capacity compared to the $Q_0$ established for the respective test, the force controlled loading sequence proposed in Task 1.3.2 was modified at low force levels. During the early loading stages, the loading history used was less than that specified in Task 1.3.2. Rather than starting at an initial force level of $0.5Q_0$, the initial primary load cycle used in Task 1.4.1.1 started at $0.4Q_0$ with a trailing load cycle of $0.3Q_0$, see **Figure 3b**. **Figure 3c** compares the force controlled loading sequence proposed by Task 1.3.2 to the sequence used in Task 1.4.1.1. Load was applied to the test specimens at an average rate of 14.3 seconds per cycle and 31.2 seconds per cycle for Test Setup 1 and 2 respectively.
Figure 3a:
Force Controlled Loading Sequence Based on Task 1.3.2

Figure 3b:
Force Controlled Loading Sequence Used in Task 1.4.1.1
Data Collection and Instrumentation

Data Collection

A data acquisition system was used to record load and displacement information for each test specimen. The data acquisition system consisted of a computer, an HP34970A Data Logger, calibrated electrical resistance strain gage load cells, cable extension transducers (CET), and linear variable differential transducers (LVDT). The load cells, CET’s and LVDT’s output signals were connected to the data logger, which is capable of reading the output signals at specific intervals dictated by the speed of the controlling computer and data logger. The computer was used to interface with the data logger. Proprietary software was used to collect the data from the data logger and transfer it to the computer hard drive. The data file was imported into an Excel spreadsheet, which converted the output signals into engineering units.

Test Load Application and Instrumentation

To measure the applied horizontal force, a load cell was placed inline with the hydraulic ram. The horizontal deflection of the test specimen was measured using a CET at the same elevation as the test load application.

Deflection and Force Measurement

At each end of the sill plate, vertical deflection of the sill plate and plywood was measured at three locations using CET’s. Vertical displacement of the sill plate was measured at opposite edges of the sill plate. The vertical deflection of the plywood was measured at the end of the sill plate. Two CET’s were used to measure the racking deflection of test specimens 18-52 by attaching the cables to diagonally opposite corners of the wall.
At each anchor bolt and hold-down (when used), the horizontal and vertical deflection of the sill plate was measured. The horizontal deflections were measured using CET’s and the vertical deflections were measured using LVDT’s. Load cells were used to measure the net tensile forces in the holdown rods and anchor bolts. See Figure 4 for general instrumentation locations.

**Graphing of Data**

After the test data was imported and converted to engineering units, graphs were created for evaluation and comparison between similar test specimens. The following graphs were created:

- load/time history,
- load/displacement at applied load
- applied load vs. sill vertical displacement at anchor bolts,
- applied load vs. sill horizontal displacement at anchor bolts,
- applied load vs. plywood vertical displacement,
- applied load vs. sill vertical displacement near plywood,
- applied load vs. sill vertical displacement opposite plywood,
- applied load vs. wall diagonal displacement.
**Figure 4:** Load Cell Locations

TEST SETUP ONE

- Load cell & LVDT at loading ram.
- CET's at diagonal cables, typical.
- Type B instrumentation at anchor bolts, typical.
- Type A instrumentation at sill at end posts, typical.
- Load cell at holdown rods, typical.

TEST SETUP TWO

- CET at sill plate
- CET at plywood

**Type A**

- CET at sill plate

**Type B**

- Load cell and CET at anchor bolt
- LVDT @ sill
Material Verification Tests

Sheathing

All plywood used in the tests was manufactured in accordance with the grade specifications of Product Standard as promulgated. Structural 1 plywood was used for all wall tests. Plum Creek Lumber Company of Columbia, Montana supplied the plywood. Each shipment of plywood was accompanied with a Certificate of Inspection. See Figure 5.

Nails

Nails were obtained from local suppliers in the Chicago, Illinois area. Nails used for the wall construction consisted of 8d and 10d common nails and 16d green vinyl sinkers (GVS). Nails were tested according to the ASTM F-1575-95, Standard Test Method for Determining Bending Yield Moment of Nails. Fifteen 8d common nails and fifteen 16d GVS nails were tested.

The 8d common nails were used to connect the plywood to the stud wall and to toenail the studs to 3x sill plates. The 8d nails were driven with a pneumatic nail gun equipped to accept full-head nails. The average length and diameter of the nails was 2.467-inches and 0.130-inches, respectively. The average bending yield strength of the 8d nails was 91.9 ksi compared to the UBC published bending yield strength of 100 ksi. This difference in bending yield strength translates into an 8% reduction in allowable single shear design values for 8d common nails based on the 1997 National Design Specification for Wood Construction (NDS). Nail bending yield strength may influence shear wall performance, however, an 8% reduction in plywood design shears should not influence sill plate-to-foundation anchorages test results.

Figure 5:
American Plywood Association - Certificate of Inspection
The 16d GVS nails were used to end nail the sill and top plates to the studs and to fasten Simpson HTT22 holdowns to the end studs. Both 16d GVS and 10d common nails were used to internail multiple studs. The 16d GVS nails were driven with hammers and the 10d nails were driven pneumatically. The average length and diameter of the 10d common nails was 3.0-inches and 0.148-inches, respectively. The average length and diameter of the 16d GVS nails was 3.25-inches and 0.148-inches, respectively. The average bending yield strength of the 16d GVS nails was 80.0 ksi compared to the published bending yield strength of 90 ksi. This difference in bending yield strength translates into an 11% reduction in allowable single shear design values for 16d GVS nails based on the 1997 National Design Specification for Wood Construction (NDS). Nail bending yield strength may influence nailed holdown and multiple end stud capacity due to reduced strength, and may slightly influence the stiffness of the holdown assembly. A slightly more flexible holdown assembly may allow the sill plate to bend and twist more than stiffer assemblies. However, the reduction in allowable design values for 16d GVS nails is viewed as not significantly affecting sill plate-to-foundation anchorages test results. Research into how prevalent low nail bending yield strength is within the woodframed construction industry, and what influence low nail bending yield strength has on shear wall assembly behavior and performance may be required in the future.

**Anchor Bolts and Power-Driven Pins**

ASTM A307 threaded rod was used for anchor bolts in the sill plate-to-foundation connections. The A307 rod had a minimum tensile strength of 60 ksi. Initially, ASTM A307 threaded rod was used for holdown rods, however to avoid possible rod failure, the holdown rods were upgraded to ASTM A320 stock which has a minimum tensile strength of 125 ksi.

Power-driven pins manufactured by the Hilti Corporation were used in the sill plate-to-foundation connections. Two different sized pins were used: X-DNI 72 pins measuring 0.145-inches in diameter and 2-7/8-inches in length and DS 72 pins measuring 0.17-inches in diameter and 2-7/8-inches in length. Power-driven pins were installed using a Hilti DX 350 piston drive tool. The drive pins were embedded through the sill plate into the concrete foundation approximately 1-1/4-inch. The tested power driven pins have an allowable shear of 180 lbs per pin. The average ultimate strength of the pins based on previous testing is about 1375 lbs per pin.

**Wood Framing**

The moisture content of the wood used for framing the walls was measured directly using a Delmhorst RDX-1 moisture meter. This instrument consists of two probes that are driven into the wood to measure the electrical resistance to calculate the moisture content. Prior to testing the specimen, the moisture content of the sills was measured near the surface and at the center. The moisture content at the surface of the sill plates ranged from 8 to 35 percent with an average moisture content of 15.6 percent. The moisture content at the center of the sill plates ranged from 9 to 56 percent with an average moisture content of 23.8 percent.

Depending on the test, sill plates were either pressure treated Douglas Fir, Southern Pine, or Hem Fir. Sill plates were selected randomly without regard to grain orientation. Information on grain orientation was collected during the tests. Grain orientation did not influence the test results.
Concrete Foundation

The simulated concrete foundations were cast using a 2000-psi compressive strength mix design. The concrete contained approximately 282-lbs. of cement, 1600 lbs. of fine aggregate, 1800 lbs. of coarse aggregate, and 29 gallons of water. The slump and air content was measured to be 2-1/4-inches and 6.2 percent, respectively. The average compressive strength of the foundations was 2365 psi at the time the wall testing began and 2475 psi at the conclusion of the tests.

The foundation was reinforced with longitudinal and transverse hoop reinforcing. The reinforcing used conformed to ASTM A615-Grade 60.
Sill Plate Anchorage Mechanics

This section of the report describes the construction of a typical shearwall, and describes two different sill plate failure mechanisms that depend on whether or not dead load and/or holdown devices are incorporated into the shearwall assembly.

Shearwall Assembly

Woodframed shearwalls are framed using 2-inch nominal thick studs, and 2-inch or 3-inch nominal thick plates, sheathed on one or both sides, and connected to the foundation with anchor bolts or power-driven pins. Typical sheathing materials are plywood, Oriented Strand Board, gypsum board, and cement plaster (stucco). The top plates of the wall assembly are connected to the floor or roof framing above. Holdowns may or may not be located at each end of the wall. Historically, anchor bolts and power-driven pins have used to connect the sill plates to the foundation with conventional washers that are 2 to 3 times the bolt or pin diameter. More recently, large square plate washers have been used with anchor bolts, and 3-inch sill plates have been used in lieu of 2-inch sill plates.

Load Transfer

When shearwalls are loaded, horizontal shear forces are transferred into the sheathing at the top of the wall, transferred out of the sheathing and into the sill plate, and transferred from the sill plate into the foundation through anchor bolts or power-driven pins. Shearwall overturning moments generate tension and compression forces in the sheathing and/or the boundary members (studs or holdown posts) at the ends of the wall. A critical area of the assembly is located toward the ends of the shearwall where not only horizontal shear forces must be transferred, but also overturning forces. If the overturning moment on the wall exceeds the dead load restoring moment, the wall tends to lift off the foundation. Holdowns can be used to resist uplift forces if dead loads are not sufficient to prevent overturning. Even when holdowns are present, the holdowns and boundary members deform when loaded, and the wall tends to lift off the foundation. Observations made during tests with and without holdowns indicate these two configurations have unique load paths and deformation patterns.

Shearwalls Without Uplift Restraint

If uplift forces are not resisted by holdowns or sufficient dead load, the net uplift forces are predominately resisted by the sheathing at the ends of the wall. Since the end studs do not have the capability to transfer any appreciable overturning load to the foundation, the end studs separate from the sill plate as the wall is loaded. As a result, overturning forces associated with the shearwall are concentrated at each end of the sill plate via the nailing of the plywood to the sill plate. Due to the inherent eccentricities between the plywood and the anchor bolts or drive pins, see Figure 6, the uplift force in the sill plate is transferred to the anchor bolt or drive pin by bending and twisting in the sill plate. The uplift force times the distance between the sheathing and the edge of anchor bolt washer generates a bending moment across the grain of the sill plate (cross-grain bending).
Depending on the shearwall assembly, either the sill plate splits, or the plywood nails pull out of the sill plate and/or pull through the plywood. Dead load applied to the shearwall reduces the net overturning force on the wall, delays the uplift of the shearwall, and delays the bending and twisting of the sill plate. Larger anchor bolt washers reduce the cross-grain bending in the sill plate. Thicker sill plates have greater cross-grain bending strength and perform better than thinner sill plates.

**Shearwalls With Uplift Restraint**

For shearwalls with uplift restraint such as holdowns, the end studs attract appreciable overturning forces, and transfer the tension component into the foundation via the holdown and transfer the compression component via bearing on the sill plate. The deformation of the plywood nails in the sill plate at early stages of loading tends to be parallel to the sill plate, which indicates that the sill plate is loaded predominately in shear. Initially, the holdown prevents the wall from uplifting, and limits bending and twisting of the sill plate.

As loads increase and the holdown assembly deforms, overturning forces are redistributed and shared between the holdowns and the plywood toward the ends of the wall based on relative rigidities. As the plywood pulls upward on the sill plate at the ends of the wall, the wall uplifts, and the sill plate bends and twists.

While holdowns allow the shearwall to achieve a higher ultimate load by delaying the uplift of the shearwall, the sill plate ultimately bends and twists similar to tests without uplift restraint. Depending on the shearwall assembly, either the sill plate splits, or the plywood nails pull out of the sill plate and/or pull through the plywood. Holdown assemblies that do not deform appreciably under load and dead load applied to the wall limit the uplift of the wall and tend to reduce bending and twisting of the sill plate. Larger anchor bolt washers reduce the cross-grain bending in the sill plate. Thicker sill plates have greater cross-grain bending strength and perform better than thinner sill plates.
Test Results

Introduction

For Task 1.4.1.1, sixty-five specimens were tested. Some specimens were tested under monotonic loading to establish target force levels, but the majority of specimens were tested under cyclic loading. A test number followed by the letter “m” indicates that a monotonic load was applied to the specimen. (For example Test 40m.) A test number not followed by the letter “m” indicates a cyclic load test. Some tests were rerun and are identified by subsequent numbers and/or letters following the test number. For example, Test 13-2 was a cyclic test with Test 13 variables. The “2” means that it is the second test. As testing progressed, additional tests were added to the test matrix. In some cases, an extra test was added considering multiple variables, and in other cases, a test was added with only one test variable modified. For these tests, the letter “x” and a possible a series of numbers follow the test number. For example, Test 10x-100 was a cyclic test with Test 10 variables, except that the dead load was changed to 100 plf. A series of tests was also run: Tests 41b through 41b-4x4.3. In this test series, the first shearwall component to fail was strengthened and a subsequent test was run. The testing and strengthening process continued until a plywood nailing-related failure occurred. Appendix 1 contains the final test matrix.

Monotonic load tests were performed in order to establish three unique $Q_0$ values. For Tests 1 through 17, which use Test Setup 1, a monotonic load was applied to test specimens 13m-2b and 13m-2c: a 3 x 6 Douglas Fir sill plate with 5/8-inch diameter anchor bolts, standard round washers, and a dead load of 134 plf. Based on the results of the tests, a value for $Q_0$ equal to 8,000 lbs. (2000 plf) was established for Tests 1 through 17.

To establish a $Q_0$ for the 8-foot by 8-foot shearwalls without holdowns, a monotonic load was applied to test specimen 40m: a 3 x 6 Douglas Fir sill plate with 5/8-inch diameter anchor bolts, 2-1/2-inch square washers, and a dead load of 100 plf. Based on the results of the test, a value for $Q_0$ equal to 3,200 lbs. (400 plf) was established for Tests 20, 21, 24 through 36, and 38 through 40.

To establish a $Q_0$ for the 8-foot by 8-foot shearwalls with holdowns, results from Test 41b-4x4.1 were used. Components of Test 41b-4x4.1 included a 2 x 4 Hem Fir sill plate, 5/8-inch diameter anchor bolts, the first anchor bolt set 20 inches from the end of wall, special 3 inch square by 1/2 inch slotted plate washers, PHD5 holdowns, 4x4 end posts, and a dead load of 100 plf. In addition, the results from tests without holdowns were reviewed, and low-level cyclic loads were applied to test specimen 22. Based on this information, a value for $Q_0$ equal to 14,000 lbs. (1,750 plf) was established for Tests 18, 19, 22, 23, 37, and 41 through 52.
For purposes of evaluating different test variables and performance levels, the test results have been placed into one of four groups:

- **Group 1**: Tests using Test Setup 1 and $Q_0 = 8,000$ lbs. Specimens are anchored to the concrete with two anchor bolts. (Tests 1 through 13)
- **Group 2**: Tests using Test Setup 1 and $Q_0 = 8,000$ lbs. Specimens are anchored to the concrete with three power-driven pins. (Tests 14 through 17)
- **Group 3**: Tests using Test Setup 2 and $Q_0 = 3,200$ lbs. Specimens are anchored to the concrete with anchor bolts; however, holdowns are not included in this series of tests. (Tests 20, 21, 24 through 36, and 38 and 40)
- **Group 4**: Tests using Test Setup 2 and $Q_0 = 14,000$ lbs. Specimens are anchored to the concrete with anchor bolts and holdowns. (Tests 18, 19, 22, 23, 37, 39, and 41 through 52)

The test results were reviewed and compared to evaluate their relative performance. Original test data and test data presented in graphical format is contained on a CD. The CD is considered part of this report. Representative samples of the data in graphical format are provided for each of the four test groups in Appendices 2 through 5.

The primary factor used in evaluating the performance of a test specimen was the number of primary loading cycles the specimen was capable of achieving. The secondary factor in evaluating the performance of a test specimen was the ultimate load the specimen was able to reach before it failed. The mode of failure was also considered in evaluating the performance of the specimen.

**Sill Plate Behavior**

During the testing, sill plates displaced laterally relative to the concrete foundation, and bent and twisted due to the inherent eccentricity between the plywood and the anchor bolts or power-driven pins. The lateral displacement of the sill varied and depended on the deformation characteristics of the sill plate and connection used to attach the sill plate to the concrete, and the ultimate load the specimen was able to reach before failure. In general, the lateral displacement was in the range of 1/16 to 1/8 inch, but was as large as 3/8-inch when specimens were able to reach ultimate loads in the range of 1,500 to 2,000 plf.

Sill plate bending and twisting was coupled and varied depending on which test variables were incorporated into a specific test. In general, the sill plates tended to split when the end of the sill plate was bent upward greater than 3/8-inch and twisted greater than 0.1 radians. Sill plate splitting was initiated at the end of the wall where the nails for attaching the end studs to the sill plate were face-nailed through the sill. The splitting propagated along the grain of the wood, from the end stud nails, through the holdown bolt hole, through and past the first anchor bolt. When sill plate splitting occurred, the specimens did not have residual strength to reach the next primary or trailing loading cycle. The specimens also tended to deflect excessively.
**Group 1 Test Results**

In an effort to evaluate how sill plates perform when loaded predominately in shear, Test Setup 1 and a \( Q_0 = 8,000 \text{ lbs.} \) was used. Tests 1 through 13 were designed to test the following sill plate-to-foundation connection variables:

- Dead load: 100 plf, 134 plf, 376 plf, and 700 plf,
- Anchor bolt washer size: Standard round washers and 2-1/2-inch square by 1/4-inch thick,
- Sill plate thickness: 2-inch nominal and 3-inch nominal,
- Sill plate width and anchor bolt size: 4-inch nominal and 6-inch nominal, and 1/2-inch and 5/8-inch diameter,

Since the horizontal applied load was located 12-inches above the sill plate for these tests, the overturning forces were approximately 1/4 of the horizontal shear forces. This test setup reduced: the uplift forces on the sill plate, the tendency for the sill plates to bend and twist, and the cross-grain bending in the sill plate. As a result, the ultimate strength of the test specimens in this group was higher than the ultimate strength of test specimens in other groups. As a reference only, the average strength of test specimens 1 through 13 was 1723 plf. The test results are summarized in Appendix 2a. Appendices 2b and 2c contain test data presented in graphical format for Tests 10 and 10x. These tests have been selected as representative samples for Group 1 tests. The original test data and test data presented in graphical format for all of the Group 1 Tests are contained on the CD noted above.

The anchor bolts for this series of tests were located along the centerline of the sill plate and conformed to the National Design Specification (NDS) end and edge distance requirements. At loads approaching the ultimate capacity of the specimen, the anchor bolts began to yield in bending and deflect in a yield mode similar to the NDS, Mode IIs, see Figure 7. The bolt holes tended to elongate, but the sill plates did not split due to horizontal shear forces.

As net uplift forces on the test specimens increased, the end of the specimen lifted off the foundation and the sill plate bent and twisted due to the uplift forces in the plywood and the inherent eccentricity between the plywood and the anchor bolts. Splitting of the sill plate occurred when the combined bending and twisting stresses in the sill plate exceeded the strength of the sill plate. When the sill plate did not split, the specimen failed when the plywood nails pulled out of the sill plate and/or pulled through the plywood.
Dead Load

With respect to the test variables considered in Group 1, the performance of the assembly was improved when a dead load of 700 plf was applied. Sill plates with 700 plf dead load were able to resist more primary cycles than sill plates with less dead load applied to the specimen. The ultimate capacity of the assembly with a 700 plf dead load was governed by plywood nail capacity and not by sill plate splitting. See Tests 3, 9, and 11-700. The sill plates tended to split when the applied dead load was less than 376 plf. See balance of tests within Group 1.

Anchor Bolt Washer Size

When larger square washers were used, the performance was modestly improved over standard round washers. See Test 10x-100 vs. Test 10, and Test 11x-100 vs. 11-100. However, in Test 11x-100, which used the 2-1/2-inch square washers, the 2 x 6 sill plate split at ultimate. The sill failed after seven primary cycles with the 2-1/2-inch square washers, whereas a sill failure occurred after six primary cycles with the round washers. In Test 10x-100, which used 2-1/2-inch square washers on a 2 x 4 sill plate, there was a plywood-related failure.

Sill Plate Thickness

With respect to sill plate thickness, 3-inch nominal plates appeared to perform better than 2-inch nominal plates. The ultimate capacity of the assembly with a 3-inch nominal sill plate was governed by plywood nail capacity while 2-inch nominal sill plates tended to split at ultimate load. See Tests 12 and 13 for data on 3-inch nominal sill plates, and Tests 1, 4, 6, 7, 10, and 11-100 for data on 2-inch nominal sill plates.

Sill Plate Width and Anchor Bolt Size

Sill plate width and anchor bolt size did not appear to significantly influence sill plate performance. Test 4 and Test 6 are similar configurations with varying sill plate widths. In both tests, the specimens were able to resist five primary cycles. Test 4 uses a 4-inch nominal sill plate and Test 6 uses a 6-inch nominal sill plate. Similarly, Test 10 uses a 4-inch nominal sill plate and Test 11-100 uses a 6-inch nominal sill plate. In both tests, the specimens were able to
resist six primary cycles. The results indicate that the strength of the assembly with 6-inch nominal sill plates is greater than the strength of the 4-inch nominal sill plates. The test specimens noted above used round cut washers.

Test 1 and Test 4 compare anchor bolt sizes, where Test 1 uses 1/2-inch diameter anchor bolts and Test 4 uses 5/8-inch diameter anchor bolts. In both tests, the specimens were able to resist five primary cycles. Similarly, Test 2 and Test 5 use 1/2-inch and 5/8-inch anchor bolts, respectively. In both tests, the specimens were able to resist six primary cycles. The test specimens noted above used 2 x 4 sill plates. The results do not show that the larger bolt diameter has consistently improved performance or greater ultimate strength.

Sill Plate Species

With respect to wood species of sill plates, there was a possible trend toward Douglas Fir being stronger than Southern Pine, and Southern Pine being stronger than Hem Fir. However, there was only a 1 percent overall difference in strength with 2 x 4 specimens and a 7 percent overall difference with 2 x 6 specimens using round cut washers. For 2 x 4 sills of different species, see Tests 1, 7 and 10 in Appendix 2. For 2 x 6 sills of different species, see Tests 3, 9, and 11-700 in Appendix 2.

Group 2 Test Results

Tests 14 through 17 were designed to test sill plate-to-foundation connections made with power-driven fasteners. In an effort to evaluate how these sill plates perform when loaded predominately in shear, Test Setup 1 and a Q₀ = 8,000 lbs. was used. The following variables were considered:

- Dead load: 100 plf, and 376 plf
- Power-driven pin size: 0.145-inch and 0.17-inch diameter

As discussed above under Group 1 Test Results, Test Setup 1 reduced the uplift forces on the sill plate, the tendency for the sill plates to bend and twist and the cross-grain bending in the sill plate. The strength of the drive-pin assembly was limited, and was controlled by the embedment depth of the drive pin and the tensile strength of the concrete. As a reference only, the average strength of test specimens 14 through 17 was 815 plf. The test results are summarized in Appendix 3a. Appendix 3b contains test data presented in graphical format for Test 17. This test has been selected as a sample for Group 2 tests. The original test data and test data presented in graphical format are contained on the CD noted above.

The lengths of the pins were approximately 2.75-inches, which resulted in a concrete embedment length of about 1.25-inches. The pins were located at least 2-inches from the edge of the concrete. The combination of shear force due to the horizontal load, uplift force due to overturning, and prying action due to the plywood-to-pin eccentricity created shear and tension on the power-driven pins. The ultimate capacity of the assembly was governed by the pullout capacity of the power-driven pins and the tensile capacity of the concrete. The combined shear and tension on the pins caused the concrete to spall toward the edge of the concrete.
Dead Load

With respect to the test variables considered in Group 2, the performance of the assembly was marginally improved when dead load was increased from 100 plf to 376 plf. With a $Q_0 = 8,000$ lbs., the specimens were only able to undergo one primary cycle. See Test 14 and 15 vs. Test 16.

Power-Driven Pin Size

When 0.17-inch diameter pins were used to fasten the sill plate to the concrete, the ultimate capacity of the specimen was higher than the capacity of a similar specimen with 0.145-inch diameter pins. See Test 17 vs. Test 16. The test specimen with the 0.17-inch diameter pins, Test 17, was able to undergo two primary cycles compared to the other test specimens that were able to undergo one primary cycle. See Test 17 vs. Tests 14, 15, and 16.

Group 3 Test Results

Tests 20, 21, 24 through 36, and 38 and 40 were designed to test the following sill plate-to-foundation connection variables:

- Sill plate thickness: 2x and 3x
- Anchor bolt washer size: Standard round, 2-inch square by 3/16-inch thick, 2-1/2-inch square by 1/4-inch thick, 3-inch square by 1/2-inch thick slotted, and Simpson LBPS 5/8 (3 inch square by 9/64 inches thick with a diagonal slot)
- Sill plate width versus washer size: 6-inch nominal sill plate
- Oversized holes in sill plate: 1/8-inch and 1/4-inch oversized holes
- Anchor bolts eccentric to the centerline of the sill plate: In 2 x 4 sill plates, 1/2-inch, and 1-inch eccentricities. In 2 x 6 sills, 1-inch, 1-1/2-inch, and 2-inch eccentricities
- Slanted anchor bolts: 5/8-inch diameter bolts with standard round washers

Test Setup 2 and a $Q_0 = 3,200$ lbs. were used to evaluate how sill plates of 8-foot high shearwalls without holdowns perform when the wall is loaded laterally, 8-feet above the sill plate. With the applied load 8-feet above the sill plate, the overturning forces are approximately equal to the horizontal shear force. As a result of the overturning forces increasing approximately 4 times compared to similar tests with Test Setup 1, the ultimate strength of the test specimens in Group 3 was significantly less than the ultimate strength of test specimens in Group 1. As a reference only, the average strength of test specimens in Group 3 was 408 plf compared to 1723 plf in Group 1. The average ultimate displacement of the test specimens in Group 3 was 4.8 inches. The test results are summarized in Appendix 4a. Appendix 4b contains test data presented in graphical format for Test 21. This test has been selected as a sample for Group 3 tests. The original test data and test data presented in graphical format are contained on the CD noted above.

Similar to Group 1 Test Results, as net uplift forces on the test specimens increased, the end of the specimen lifted off the foundation and sill plate bent and twisted due to the uplift forces in the plywood and the inherent eccentricity between the plywood and the anchor bolts. With limited exception, the sill plate split when the combined bending and twisting stresses in the sill plate exceeded the strength of the sill plate. Only two plywood-related failures occurred: in Test
38, which had a 3 x 4 sill plate and used 2-1/2-inch square washers, and Test 27, which had a 2 x 4 sill plate and used 2-1/2-inch square washers. In general, sill plate thickness, and washer size and thickness had the greatest influence on the performance of assemblies without uplift restraints, such as holdowns.

Sill Plate Thickness

With respect to the test variables considered in Group 3, the highest performance level was achieved when 3-inch nominal sill plates were used in combination with 2-1/2-inch square by 1/4-inch thick washers. Three-inch nominal sill plate test specimens with 2-1/2-inch square washers were able to undergo 15 to 20 primary cycles before failure and reach ultimate loads of 530 to 645 plf. See Tests 38 and 40.

Anchor Bolt Washer Size

Washer thickness influenced the performance of the sill plate-to-foundation connections. If the washers yielded as the sill plate bent and twisted, the washers were less effective in reducing cross grain bending in the sill plate. As a result, sill plates with thicker washers failed after more primary cycles and at higher ultimate load than sill plates with washers that yielded during the test. See Figure 8.

In general, anchor bolts with 2-1/2-inch square washers performed better than anchor bolts with 2-inch square by 3/16-inch thick washers (2-inch square washers). Test specimens with 2 x 4 sill plates and 2-1/2-inch square washers were able to undergo 10 to 12 primary cycles before failure and reach an average ultimate load of 456 plf. See Tests 21 and 38x. In contrast, 2 x 4 sill plate test specimens with 2-inch square washers were able to undergo 8 to 9 primary cycles before failure and reach an average ultimate load of 380 plf. See Tests 20 and 24.

Three-inch square by 1/2-inch thick slotted plate washer test specimens were able to undergo 9 primary cycles before failure and reach an ultimate load of 403 plf, compared to similar size slotted washers that were only 9/64-inches thick that were able to undergo 8 primary cycles and reach an ultimate load of 371 plf. Bolt offset from sill plate centerline may have also affected the ultimate capacity of the test specimens. See Tests 32 and 33.
The performance of 2 x 6 sill plates did not appear to be influenced by washer size in the 2-inch to 2-1/2-inch square range. For Test 25 and 40x, a 2 x 6 test specimen with 2-1/2-inch square washers, was able to undergo 7 to 8 primary cycles before failure and reach an average ultimate load of 360 plf. For Test 24, a two- by-six test specimen with 2-inch square washers was able to undergo eight primary cycles before failure and reach an average ultimate load of 370 plf. However, the performance of 2 x 4 sill plates with 2-inch and 2-1/2-inch washers was better than the performance of similar 2 x 6 sill plates with 2-inch and 2-1/2-inch washers. For Test 20, a 2 x 4 test specimen with 2-inch square washers was able to undergo nine primary cycles before failure and reach an average ultimate load of 391 plf. In comparison, for Test 24, a 2 x 6 test specimen with 2-inch square washers was able to undergo eight primary cycles before failure and reach an average ultimate load of 370 plf. For Test 21, a 2 x 4 test specimen with 2-1/2-inch square washers was able to undergo 12 primary cycles before failure and reach an average ultimate load of 480 plf. In contrast, for Test 25, a 2 x 6 test specimen with 2-1/2-inch square washers was able to undergo only seven primary cycles before failure and reach an average ultimate load of 336 plf.

**Oversized Holes in Sill Plate (1/8-inch and 1/4-inch larger diameter than bolt)**

Test results for specimens with oversized bolt holes drilled in the sill plates and 2-1/2-inch square washers indicate that the performance is not influenced by oversized holes. Similarly, test results for specimens with oversized anchor bolt holes filled with epoxy and 2-1/2-inch square washers indicate that the performance is not influenced by the oversized holes filled with epoxy. See Tests 29, 30, 26, and 27. The performance level in all four cases was similar to 2 x 4 sill plates with 2-1/2-inch square washers. Test specimens with oversized bolt holes and oversized
bolt holes filled with epoxy were able to undergo 10 to 12 primary cycles before failure and reach an average ultimate load of 450 plf.

**Anchor Bolts Eccentric to the Centerline of the Sill Plate**

Tests were conducted to evaluate the effect of anchor bolts placed eccentric from the centerline of the sill plate, and away from the edge of the sill plate with plywood. See Figure 9. Test results for specimens with anchor bolts located eccentrically from the centerline of the sill plate indicate that the performance is influenced by the width of the sill plate, the size and thickness of the washer, and the magnitude of the eccentricity. See Tests 32 through 36. Two-by-four sill plates performed better than 2 x 6 sill plates. Minor eccentricities, up to 1-inch for 2 x 4 sill plates and 1-1/2-inches for 2 x 6 sill plates, moderately influenced the performance of the sill plate, reducing the number of primary cycles but not significantly reducing the ultimate capacity. However, the performance of Test 34, with 1/2-inch diameter bolts 2-inches off center in a 2 x 6 sill plate, was notably reduced.

![Figure 9](image)

In general, sill plates with the greatest eccentricity performed the poorest; however, performance is improved when stronger and stiffer washers are used. The performance of a sill plate was improved when a 3-inch square by 1/2-inch thick slotted plate washer (3-inch slotted washer) was used in lieu of the Simpson LBPS 5/8 washer hardware. The 9/64-inch thick Simpson LBPS 5/8 tended to yield and deform while the 1/2-inch thick slotted washer remained essentially elastic with no visible deformation.

The 2 x 4 sill plate with anchor bolts offset by 1-inch, but with a 3-inch square slotted washer performed the best within this series of tests. See Test 33. This test specimen was able to undergo nine primary cycles before failure and reach an ultimate load of 403 plf. In contrast, the poorest performing test specimen utilized a 2 x 6 sill plate, 1/2-inch anchor bolts offset 2-inches, and Simpson LBPS 5/8 washers. See Test 34. This test specimen was only able to undergo three primary cycles before failure and reach an ultimate load of 240 plf.
Slanted Anchor Bolts

Slanted anchor bolts tests, Tests 28 and 31, used standard round washers. These tests used 5/8-inch anchor bolts that were installed at an angle of 26.6 degrees with respect to the plane of the wall. The performance of the specimens appeared to be influenced more by washer and sill plate width than by the installation of the anchor bolts at an angle. The test specimens were able to undergo 5 to 6 primary cycles before failure and reach an average ultimate load of 317 plf.

Group 4 Test Results

In an effort to evaluate how sill plates of 8-foot high shearwalls with holdowns perform when the wall is loaded laterally 8-feet above the sill plate, Test Setup 2 and $Q_0 = 14,000$ lbs. were used. Tests 18, 19, 22, 23, 37, 39, and 41 through 52 were designed to test the following sill plate-to-foundation connection variables.

- Anchor bolt washers: Standard round, 2-inch square by 3/16-inch thick, 2-1/2-inch square by 1/4-inch thick, 3-inch square by 1/2-inch thick slotted, 3-inch square by 1/4-inch thick, 3-inch square by 3/16-inch thick, and 5-inch square by 1/2-inch thick.
- Sill plate thickness: 3-inch nominal
- Holdown type: Simpson HTT22, Simpson PHD5
- Location of first anchor bolt from end of shearwall: 8-inches and 20-inches
- Special sill plate-to-foundation connections: Rods without nuts and washers, and retrofitted 2 x 4 walls with 2 x 6 sill plates

With the applied load 8-feet above the sill plate, the overturning forces are approximately equal to the horizontal shear force. The holdowns tended to delay sill plate uplift, bending and twisting of the sill plate, and the development of cross-grain bending stresses. As a result, the ultimate strength of the test specimens in Group 4 was higher than the ultimate strength of test specimens in Group 3. For reference only, the average strength of test specimens in Group 4 was 1210 plf compared to 408 plf in Group 3. The average ultimate lateral displacement at the double top plates of the test specimens in Group 4 was 5.1 inches.

The number of primary cycles the specimens within Group 4 was able to resist before failure was generally less than the number of primary cycles the specimens within Group 3 were able to resist. This is because the $Q_0 = 14,000$ lbs for Group 4 was more than 4 times larger than the $Q_0 = 3,200$ lbs for Group 3. If $Q_0 = 3,200$ lbs was selected for Group 4, the number of primary cycles that the specimens would have been able to resist before failure would greatly exceed the maximum number of primary cycles (20) reached in Group 3. Similarly, if $Q_0 = 14,000$ lbs was selected for Group 3, all of the test specimens would have failed within the first primary cycle (5,600 lbs.).
Because the overturning forces associated with Test Setup 2 are approximately 4 times the overturning forces associated with Test Setup 1, and since the holdowns only delayed sill plate uplift, Group 4 test specimens were not able to reach the same level of performance as Group 1 specimens. For reference only, the average strength of test specimens in Group 4 was 1210 plf compared to 1723 plf in Group 1. Group 4 test results are summarized in Appendix 5a. Appendices 5b, 5c, and 5d contain test data presented in graphical format for Tests 19, 42, and 51. These tests have been selected as representative samples for Group 4 tests. The original test data and test data presented in graphical format are contained on the CD noted above.

Test specimens in Group 4 were installed with either Simpson HTT22 or PHD5 holdowns. The performance of these shearwalls was greatly improved over similar shearwalls without holdowns. The holdowns tended to transfer the overturning forces at the ends of the wall directly into the foundation, and to delay the uplift of the wall, and the subsequent bending and twisting of the sill plate. In general when full width washers of adequate thickness were used in conjunction with Simpson PHD5 holdowns, the sill plates did not split, and the ultimate capacity of the specimen was controlled by failure of another component of the shearwall.

Tests 41b, 41-4x4.1, 41-4x4.2 and 41-4x4.3 were extremely beneficial in identifying the potential weak links in a shearwall assembly. For this series of tests, 2 x 4 shearwalls with 3-inch square by 1/2-inch thick slotted plate washers and Simpson PHD5 holdowns were tested. The 5/8-inch diameter anchor bolts were located 20-inches from the end of the wall. In Test 41b, the end studs were double 2 x 4’s that were internailed with 6-16d GVS nails (0.148 inch diameter). After undergoing one primary cycle and reaching a load of 927 plf, the double 2 x 4 end studs split. In test 41b-4x4.1, 4 x 4 end posts were used in lieu of double 2 x 4’s. Due to a technical error in the loading ram, the specimen was loaded monotonically up to failure in about 1 minute. The specimen reached an ultimate load of 14,061 pounds or 1758 plf before the 2-by stud at the plywood joint in the center of the specimen failed. In test 41b-4x4.2, 4 x 4 end posts were once again used in lieu of double 2 x 4’s. After undergoing three primary cycles and reaching an ultimate load of 1041 plf, the 2-by stud at the plywood joint in the center of the specimen failed. For the final test in the series, Test 41b-4x4.3, 4 x 4 end posts were used and a 4 x 4 stud was used at the plywood joint in the center of the specimen. Test specimen 41b-4x4.3 was able to undergo six primary cycles and reached an ultimate load of 1576 plf before the plywood nails pulled through the plywood.

Test 44 also identified a potential weak link in the shearwall assembly. The specimen was a 2 x 6 stud shearwall with double 2 x 6 end studs. The studs were internailed with a double row of 10d common nails (0.148 inch diameter) at 3-inches on center. After undergoing 3 primary cycles and reaching an ultimate load of 1046 plf, the double 2 x 6 end studs split along the row of 10d common nails that were closest to the plywood sheathing side of the stud, where the plywood nails terminated in the stud.

**Anchor Bolt Washers**

With respect to the test variables considered in Group 4, the performance of the sill plate assembly was improved when washers that were essentially the same width as the sill plate were used. Test specimens with full width washers did not exhibit sill plate failures at ultimate load.
The best performing assemblies were 2 x 4 shearwalls with 3-inch square by 1/2-inch thick slotted plate washers and Simpson PHD5 holdowns. See Tests 41-4x4.3 and 42. In both tests, the sill plate did not split and plywood nails pulling through the plywood or the wall softening to +/- 6-inches, which was the limit of the loading ram, controlled the ultimate capacity of the specimens. Both tests were able to undergo six primary cycles and reached an average ultimate load of 1560 plf. For Test 45, the 2 x 6 stud shearwall had 5-inch square by 1/2-inch thick washers and Simpson PHD5 holdowns. In this test, the sill plate did not split and the plywood nails pulling out of the sill plate or pulling through the plywood controlled the ultimate capacity of the specimen. For Test 45, the assembly was able to undergo four primary cycles and reached an ultimate load of 1215 plf.

**Sill Plate Thickness**

Three-by-four and 3 x 6 sill plates were tested using 2-1/2-inch square washers, and either Simpson HTT22 or PHD5 holdowns. See Tests 37 and 39. In both tests, the sill plate did not split and the ultimate capacity of the specimens was controlled by end post splitting, or end post failure at a knot. Both tests were able to undergo four primary cycles and reached an average ultimate load of 1209 plf.

**Holdown Type**

Two types of holdowns were used in the tests. HTT22 holdowns are attached to the holdown stud with 32-16d GVS nails (0.148 inch diameter). The PHD5’s are attached with 14-1/4 inch wood screws. The specified ultimate strength of the PHD5 is slightly higher than the HTT22, 15,670 pounds versus 13,150 pounds. The PHD5 has a specified deflection at allowable design load that is less than the deflection of the HTT22, 0.047-inch versus 0.087-inch.

The test results indicate that the specimens with the PHD5 holdowns experienced less uplift at the ends than the specimens with the HTT22 holdowns. As a result, the specimens with the PHD5 holdowns experienced less splitting and achieved higher ultimate loads. In two of the tests, Test 48 and 50, the HTT22 failed along the bottom row of nails.

**Location of First Anchor Bolt from End of Shearwall**

The location of the first anchor bolt from the end of the shearwall was also considered a test variable. Moving the first anchor bolt further from the end of the wall allows for more flexibility of the sill plate between the end of the wall and the restraint provided by the first anchor bolt. The first anchor bolt was located either 8-inches or 20-inches from the end of the wall. The performance of the shearwalls did not appear to be significantly influenced by the location of the first anchor bolt. Washer size and thickness described above were more influential. For Tests 41b-4x4.3, the first anchor bolt was located 20-inches from the end of the wall and for Test 42, the first anchor bolt was located 8-inches from the end of the wall. Both tests were able to undergo six primary cycles. Test 41b-4x4.3 reached an ultimate load of 1576 plf, and Test 42 reached an ultimate load of 1545 plf. For Tests 18 and 19, smooth rods were used in lieu of anchor bolts with nuts and washers. For Test 18, the first rod was located 20-inches from the end of the wall and for Test 19, the first rod was located 8-inches from the end of the wall. Both tests were able to undergo four primary cycles. Test 18 reached an ultimate load of 1222 plf, and Test 19 reached an ultimate load of 1226 plf.
**Special Sill Plate-to-Foundation Connections**

A series of tests were run where smooth rods or threaded rods without nuts and washers were used in lieu of anchor bolts with nuts and washers. See Tests 18, 19, 22-4c, and 23. While the number of primary cycles the specimens were able to undergo appeared to remain the same or slightly improve when rods were used in lieu of anchor bolts with nuts and washers, the failure mode for the shearwall assembly with rods was always sill plate splitting.

Another series of tests was run where a 2 x 4 stud wall was framed onto a 2 x 6 sill plate. The sill plate was bolted to the simulated foundation with 5/8-inch diameter anchor bolts, nuts and standard washers. Blocking was installed between studs. The blocking was nailed and not bolted to the sill plate. Oversized holes (1-1/8 inch diameter) were cut in the blocking around the anchor bolts and nuts that extended above the sill plate. Plywood was nailed to the stud framing and into the blocking. See Figure 10. The plywood was not nailed to the sill plate. With this assembly, horizontal forces were transferred from the blocking to the sill plate via nails, and ultimately to the foundation via the anchor bolts in the sill plate. Overturning related forces were transferred to the foundation via the holdowns. When 2-inch nominal blocking was nailed to the sill plate with 8d common nails at 3 inches on center (6 nails per block), Tests 47 and 48, the ultimate load on the shearwall was reached when the blocking split and failed. However, when 3-inch nominal blocking was nailed to the sill plate with 20d (0.148 inch diameter) galvanized box nails (6 nails per block), Test 49, the ultimate load on the shearwall was reached when plywood nails pulled out of the blocking or pulled through the plywood. The latter mode of failure was considered an improvement over splitting of the blocking between studs. For Test 49, the specimen was able to undergo five primary cycles, and reach an ultimate load of 1410 plf.

**Figure 10:**

*2 x 6 Sill with 2 x 4 Blocking*
Discussion

Target Ultimate Capacities

Each group of tests was considered to have a unique target capacity due to the differences in overturning moments or by the introduction of holdowns to resist overturning. In order to establish target ultimate capacities for groups of tests subjected to cyclic loads, monotonic tests were run on selected test specimens. The procedure was consistent with the force controlled loading protocols developed in Task 1.3.2 Testing Protocols of the CUREE-Caltech Woodframe Project. For tests 1 through 17, which used Test Setup 1, a value of Q₀ equal to 8,000 lbs (2,000 plf) was established based on the results of Tests 13-m2a, 13-m2b, and 13-m2c. Similarly, for tests on 8-foot long by 8-foot high shearwalls without holdowns, Test Setup 2 was used and a value of Q₀ equal to 3,200 lbs (400 plf) was established based on the results of Test 40m. For tests on 8-foot long by 8-foot high shearwalls with holdowns, Test Setup 2 was used and a value of Q₀ equal to 14,000 lbs (1,750 plf) was established.

The primary reason for Q₀ ranging from 2,000 plf for Test Setup 1 down to only 400 plf for Test Setup 2 without holdowns is due to uplift effects on the sill plates due to overturning. When horizontal loads are applied close to the sill plate, or when holdowns are used in 8-foot high shearwalls, the net uplift component in the plywood due to overturning moments is less than the net uplift component in the plywood of 8-foot high shearwalls without holdowns. For a given horizontal force, the walls without holdowns tend to immediately lift off the foundation. In turn, the sill plates bend and twist earlier in the loading cycle and ultimately fail at a lower force level than other test setups.

Performance Criteria

The acceptable seismic performance of an assembly is judged considering the ability of the assembly to absorb energy in a ductile manner, or the ability of the assembly to resist seismic demands without brittle failure. As discussed earlier, the primary factor used in evaluating the performance of a sill plate-to-foundation anchORAGE was the number of primary loading cycles the specimen was capable of achieving. The secondary factor in evaluating the performance was the ultimate load the specimen was able to reach before it failed. Another factor that was considered in evaluating the performance of an anchorage was the mode of failure. Because sill plate-to-foundation anchorages are considered non-ductile, the force controlled loading protocols were applied to the test specimens, and not the displacement controlled protocols. The primary objective of Task 1.4.1.1 was to develop more reliable sill plate-to-foundation anchorages that are able to resist the seismic demands without brittle failure.

The acceptable performance of a shearwall assembly could be evaluated based on the ability of an assembly to absorb energy, which would be a function of the force and displacement characteristic of the assembly. Shearwall assemblies with holdowns, Group 4, had an average ultimate capacity of 1,210 plf and an average ultimate displacement of 5.1 inches. In contrast, the shearwall assemblies without holdowns, Group 3, had an average ultimate capacity of 408 plf and an average ultimate displacement of 4.8 inches. Shearwall assemblies with holdowns have greater force and displacement capacity compared to shearwall assemblies without holdowns. Qualitatively, shearwall assemblies should be able to absorb more energy than shearwall
assemblies without holdowns. As a result, one could conclude that shearwall assemblies with holdowns should perform better than shearwall assemblies without holdowns.

**Sill Plate Behavior**

Sill plates tend to split when the combined bending and twisting of the sill plate induces stresses in the sill plate that exceed the ultimate strength of the sill plate. Sill plate bending and twisting occurs when overturning forces exceed dead load restoring forces and when deformations in holdown assemblies are large. As the wall uplifts, the plywood pulls upward on the edge of the sill plate and the sill plate lifts off the foundation and bends. In addition, due to the eccentricity between the plywood and the anchor bolts in the sill plate, the sill plate also twists. The twisting induces cross grain bending stresses into the sill plate. The tests indicate that to improve the performance of sill plate anchorages, bending of the sill plate as well as twisting, and cross grain bending should be minimized. Sill plate uplift can be minimized by optimizing the dead load acting on the wall and by installing holdowns. Sill plate twisting and cross grain bending can be minimized by increasing the size and thickness of anchor bolt washers or increasing sill plate thickness. Further, plywood could be installed on both faces to minimize sill plate twisting due to the inherent eccentricity between the plywood and the anchor bolts. Walls sheathed with plywood on both sides were not a test variable under Task 1.4.1.1. Further research is required in this area.

Deformations associated with sill plate uplift, bending and twisting varied from test to test, and were different at each end of a test specimen. However, the test results would suggest that sill plates tend to split when the end of the sill plate was bent upward greater than 3/8-inch and twisted greater than 0.1 radians. This information should be considered tentative and only used as a reference. Additional research is required in the area of combined bending and twisting of sawn timber.

Tests with 2-1/2-inch square and 3-inch square washers and Simpson HTT22 holdowns have shown that sill plate uplift can be delayed, however, the holdowns do not have the required stiffness at ultimate to prevent the sill plate from splitting. Tests with Simpson PHD5 holdowns and 3-inch square washers have shown that sill plate bending, twisting, and cross grain bending can be minimized to a point where the ultimate capacity of the shearwall is not based on sill plate strength but based on capacities of other shearwall components.

**Test Results Compared to UBC Allowable**

As presented above in the Test Results section, for purposes of evaluating different test variables and performance levels, the test results were placed into one of four groups. For Group 1, horizontal loads were applied 12-inches above the sill plate of a 4-foot long specimen, which was attached to a simulated foundation with anchor bolts. The height-to-width ratio of these specimens was 1 to 4. For reference purposes only, the average ultimate strength of test specimens within Group 1 was 1723 plf. For Group 2, horizontal loads were also applied 12-inches above the sill plate of a 4-foot long specimen which was attached to a simulated foundation with power-driven pins. The height-to-width ratio of these specimens was 1 to 4. For reference purposes only, the average ultimate strength of test specimens within Group 2 was 815 plf.
For Group 3, horizontal loads were applied 96-inches above the sill plate of an 8-foot long specimen which was attached to a simulated foundation with anchor bolts. Specimens within Group 3 did not include holdowns. The height-to-width ratio of these specimens was 1 to 1. For reference purposes only, the average ultimate strength of test specimens within Group 3 was 408 plf. For Group 4, horizontal loads were also applied 96-inches above the sill plate of an 8-foot long specimen which was attached to a simulated foundation with anchor bolts. Specimens within Group 4 included holdowns. The height-to-width ratio of these specimens was 1 to 1. For reference purposes only, the average ultimate strength of test specimens within Group 4 was 1210 plf.

The test specimens were designed using UBC allowable design loads for the anchor bolts with a target design load of 1120 pounds for a 5/8-inch diameter bolt. This corresponds to 2240 pounds for the 4-foot walls with 2 anchor bolts in Test Setup 1 and 4480 pounds for the 8-foot walls in Test Setup 2 with 4 anchor bolts, or 560 plf. The ultimate target load was estimated at 1680 plf based on an assumed factor of three between ultimate and design loads. The plywood nailing and holdowns were designed to approximately equal or exceed the target design load. The simulated concrete foundation and the testing apparatus were designed stronger than the ultimate strength of the test specimens.

The test results compared to the approximate ultimate target strength of a shearwall based on UBC allowable design loads would suggest the following:

- On average, test specimens within Group 1 developed strengths greater than the assumed ultimate target load, 1723 plf vs. 1680 plf. This would suggest that shearwalls with height-to-width ratios of 1 to 4 and sufficient dead load should perform satisfactorily. The aspect ratio and the dead load reduce the uplift at the ends of the shearwall. Without significant uplift, the sill plate or the anchor bolt does not govern the behavior of the sill plate assembly bolt. Instead, the strength is controlled by the strength of the other components of the shearwall.

- Comparing test results from Group 1 with Group 2, which both used Test Setup 1 and a $Q_0 = 8,000$ lbs, illustrates the relative poor performance of power-driven pins compared to anchor bolts, 1723 plf vs. 815 plf. The results for the Group 2 tests would be expected to be less than Group 1 based on a comparison of allowable and ultimate values for 3 power-driven pins compared to 2 anchor bolts. Three power-driven pins have an allowable load that is about 25 percent of the two anchor bolts and an ultimate value that is about 60 percent of the two anchor bolts. Shearwalls with power-driven pins were not able to resist multiple primary loading cycles, and did not have the strength equal to that of walls with anchor bolts. The walls tested using three power-driven pins were only able to resist 1 or 2 primary loading cycles compared to a minimum of 5 primary cycles for Group 1 test specimens with 2 anchor bolts. In addition, the strength of Group 2 specimens was only about one-half of the strength of Group 1 specimens. One of the factors that affected the strength of the walls with power-driven pins was the pullout of the pins caused by combined uplift and prying action of the sill plate.
• On average, test specimens within Group 3 developed strengths that were substantially less than the assumed ultimate target load, 408 plf vs. 1680 plf. This would suggest that, aside from the issue of sill plate splitting-related failures, design values for shearwalls without holdowns and with height-to-width ratios of 1 to 1 should be lowered to reflect the lower capacity of Group 3 shearwalls, or shearwall height-to-width ratios should be reduced and approach 1 to 4 as discussed above.

• On average, test specimens within Group 4 developed higher strengths than Group 3, but the average strength did not exceed the assumed ultimate target load, 1210 plf vs. 1680 plf. This would also suggest that design values for shearwalls with holdowns and with height-to-width ratios of 1 to 1 should be lowered to reflect the lower capacity of Group 4 shearwalls, or shearwall height-to-width ratios should be slightly reduced.

Failure Modes

While the primary objective of Task 1.4.1.1 was to evaluate the performance of sill plate-to-foundation anchorages, the performance of other shearwall components was also noted during the tests. The types of failures observed during the tests included: sill plate splitting; splitting of holdown studs or posts; holdown failures; splitting of studs at plywood panel joints; and plywood nails pulling out of sill plates or through the plywood. Test results from similar tests within the CUREE-Caltech Woodframe Project have not identified some of the failure modes noted during Task 1.4.1.1. One possible explanation for different failure modes with similar tests could be the way in which loads are applied to the test specimens. For Task 1.4.1.1, loads were applied through a pinned connection welded to a 1/2-inch thick plate that was bolted to the specimen. The pinned connection was located at the centerline of the wall. This loading method provided symmetrical loading, allowed the specimen to rock, and minimized secondary restraints on the specimen. See Figures 1a, 1b, 2a and 2b. Other shearwall tests outside Task 1.4.1.1 utilized stiff loading beams bolted to the top of the specimen. Additional research is needed to better understand how loading assemblies affect test results.

Sill Plate Splitting

Sill plate splitting was the most common mode of failure. At the ends of the sill plate, normal wood checks and splits were noted in some of the sill plates prior to fabrication. After assembly, the ends of the sill plate tended to be slightly split due to nails driven through the sill plate into the ends of the studs. These initial splits at the end of the sill plate acted as stress risers when the specimens were tested. As load was applied to the specimen, and the sill plate began to bend and twist, cracks in the sill plate tended to propagate along the grain of the wood, from the end stud nails, through the holdown bolt hole, through and past the first anchor bolt. As discussed above, full width washers, dead load, and holdowns tended to delay uplift of the specimen that cause bending and twisting of the sill plate. When bending and twisting of the sill plate was delayed, the failure mechanism shifted to other shearwall components. In some tests, as other components failed, such as holdowns, uplift forces were transferred to the sill plate, which in turn caused the sill plate to split. See Figure 11.
Splitting of Holdown Studs and Posts

Holdowns were either nailed or screwed to 2-inch nominal double end studs or 4-inch nominal posts. When double end studs were nominally nailed together with 6-16d GVS nails, and the plywood was nailed to the outer stud, the double studs did not act as a unit. During testing, the studs slid past one another, which caused the fasteners for the holdown to rotate. The fastener rotation caused the studs to split through the fastener group. See Figures 12a, 12b and 12c.

Figure 12a:
Double End Post Slippage
When the double studs were internailed with a double row of 10d common nails at 3-inches on center, the studs split along the row of fasteners that were closest to the plywood face of the wall. The row of 10d nails coincided with the tips of the plywood nails and created a weakened plane. See Figures 13a and 13b.
Figure 13a:
End Holdown Stud Split at Stud Internailing Line

Figure 13b
Double End Post Interconnection

8d PLYWOOD NAILS @ 3" o.c. TO OUTER STUD, SEE FIGURE 10b.

10d @ 3" o.c. DOUBLE ROW
In Tests 51 and 52, 4-inch nominal end posts were used in conjunction with Simpson PHD5 holdowns. The screws caused the end posts to split prematurely during loading. The split in the end post usually occurred along the row of lag screws that was located closest to the plywood sheathing side of the post. The lag screws created a weak plane in the end post. See Figures 14a and 14b. When 4-inch nominal end posts were used in conjunction with Simpson HTT22 holdowns, the nails did not cause the end posts to split. However, as discussed below, the HTT22 failed. Further research is required in this area.

**Figure 14a:**
Split 4x Holdown Post

![Split 4x Holdown Post](image)

**Figure 14b:**
Split 4x Post at Holdown Fastener Line

![Split 4x Post at Holdown Fastener Line](image)
Holdown Failure

During tests that incorporated Simpson HTT22 holdowns, some of the holdowns failed. The failure occurred along the first set of nails from the bottom of the holdown. See Figure 15. Simpson PHD5 holdowns did not fail during the tests. Further research is required in this area.

Stud Splitting at Panel Joints

During Tests 41b-4x4.1 and 41b-4x4.2, the 2 x 4 stud at the vertical plywood panel joint split during testing. See Figures 16a and 16b. For Test 41b-4x4.3, a 4 x 4 post was used at the vertical panel joint in lieu of a 2 x 4 stud. For Test 41b-4x4.3, the 4 x 4 post did not split and the failure of the shearwall was due to plywood nails pulling through the plywood. It should be noted that for the plywood nailing scheduled used in these tests (8d common at 3 inches on center), the 1997 edition of the Uniform Building Code (UBC) would require 3x minimum studs at vertical panel joints. Based on these test results, the UBC provision appears appropriate.

Plywood Nail Related Failures

During some of the tests, plywood related failures occurred. Plywood nails pulled out of the sill plate and/or pulled through the plywood. See Figure 17. When nails were pulled out of the sill plate, it appeared that the cyclic loading caused successive nail withdrawal from the sill.
Figure 16a:
Split Stud at Panel Joint

Figure 16b:
Split Stud at Panel Joint
Test Variables

Test variables that were evaluated in Task 1.4.1.1 are discussed below. Due to the limited number of test specimens, not every test variable was isolated and several test variables may have been grouped into a series of tests. However, the tests were beneficial in that the mechanics of sill plate anchorages of shearwalls is better understood, and the factors that significantly influence the performance of sill plate-to-foundation connections have been identified.

Washer Size and Thickness

The test results indicate that washer size, and thickness influences the behavior and performance of sill plates. Washer size had a significant influence on sill plate performance. Three inch square washers on 2 x 4 sill plates, and 5-inch square washers on 2 x 6 sills reduced twisting and the affects of cross grain bending in the sill plate. Washer thickness also played an important role in improving sill plate performance. Washers that did not yield during the tests also reduced sill plate twisting, and the affects of cross grain bending. When the washers yielded, the behavior of the sill plate was similar to tests with smaller washers. The influence that wider and thicker washers had on sill plate performance was greater for 2 x 4 sill plates than for 2 x 6 and 3-inch sill plates.

The performance of specimens with rods without nuts and washers was similar to specimens with standard round washers. Friction developed between the sill plate and the rod was sufficient to prevent the sill plate from sliding up and down on the rod. As a result, the sill plate uplifted and twisted, which ultimately caused the sill plate to split.

Based on the test results, full width washers of ample thickness improved the performance of the sill plate-to-foundation connections. The washers reduce the twisting and cross-grain bending in the sill plate.
Holdown Type

Simpson PHD5 and HTT22 holdowns were used in selected tests to resist the uplift forces associated with shearwalls. PHD5 holdowns are specially constructed to reduce the deflection of the assembly when loaded. The allowable strength of PHD5 and HTT22 holdowns are similar (4500 pounds vs. 5250 pounds), but the deflection of the PHD5 at design loads is less than the HTT22 (0.047-inch vs. 0.087-inch). The test results demonstrate that holdowns delay sill plate uplift. However, as the applied loads on the wall increase, uplift loads in the boundary elements and holdown assemblies’ increase causing the holdown assembly to elongate, which in turn allows the sill plate to lift off the foundation. Depending on the strength and stiffness of the holdown assembly, the sill plate may not be subjected to significant cross grain bending and sill plate splitting may not occur. Holdowns assemblies should be stiff enough to limit sill plate uplift, and strong enough to adequately transfer the overturning related forces from the shearwall to the foundation.

As discussed above, during tests that incorporated Simpson HTT22 holdowns, some of the holdowns failed. The failure occurred along the first set of nails from the bottom of the holdown. Simpson PHD5 holdowns did not fail during the tests. However, in some of the tests, the end post split along the row of lag screws that secure the PHD5 to the post. Further research and testing is required in this area.

Sill Plate Thickness and Width

Three-inch nominal sill plates performed better than 2-inch nominal sill plates because the cross grain bending strength of 3-inch nominal sills is greater. Two-by-four sill plates performed better than 2 x 6 sill plates and 3 x 4 sill plates performed better than 3 x 6 sill plates. This is because the eccentricity between the plywood and the anchor bolts located along the centerline of the sill, which causes cross grain bending stresses in the sill, is greater in 5.5-inch wide sills than in 3.5-inch wide sills.

Shearwall performance can be improved by using 3-inch nominal thickness sill plates and by using 4-inch nominal width sill plates.

Wood Species

Research into published cross grain tensile strength of Douglas Fir, Southern Pine and Hem Fir indicated that Douglas Fir is stronger than Southern Pine, and the Southern Pine is stronger than Hem Fir. Tests performed under Task 1.4.1.1 suggest a possible trend that is consistent with the published information. However, the number of tests performed under this task is not sufficient to establish a statistically meaningful comparison among the species tested. Additional shearwall tests may demonstrate that there is no significant difference in shearwall performance based on wood species of the sill plate.
**Foundation Material**

All specimens were attached to a simulated foundation. The concrete for the foundations was designed to reach a 28-day compressive strength of 2000 psi and then level off. At the beginning of the tests, the compressive strength was approximately 2365 psi. After all tests were completed, the compressive strength was approximately 2475 psi. Concrete related failures did not occur during any of the tests with the exception that spalling occurred when power-driven pins were used to attach the sill plate to the foundation.

**Bolt Diameter**

Two different size anchor bolts were evaluated: 1/2-inch diameter, and 5/8-inch diameter. The test results varied depending on the magnitude of the dead load applied to the specimen. Tests with a dead load of 100 plf suggest the 1/2-inch diameter anchor bolts perform slightly better than 5/8-inch diameter bolts. However, tests with a dead load of 376 plf suggest the opposite.

Considering the test results using Test Setup 1 and observations made during the tests, the performance of shearwalls is not influenced by anchor bolt size. This result conflicts with building code design, which provide higher allowable forces for larger diameter anchor bolts. The 1/2-inch and 5/8-inch diameter anchor bolts have the capacity to resist the applied loads without failure of the bolts. While some anchor bolts yielded during the tests, bolt behavior did not contribute to sill plate splitting.

**Dead Load**

Dead loads acting on shearwalls keep the end studs in contact with the sill plate and the sill plate in contact with the foundation. As horizontal loads are applied to the top of the shearwall, overturning forces that cause the sill plate to lift off the foundation are created. When the overturning forces exceed the dead load acting on the shearwall, the sill plate will uplift. The effect that dead load has on the behavior of shearwalls is that it delays the uplift of the wall, and as a result, higher ultimate loads can be reached. Larger values of dead loads on a shearwall improve the performance of the shearwall, as demonstrated in Group 1 tests.

**Bolt Location – Edge and End Distance**

Anchor bolts that were concentric and eccentric to the centerline of the sill plate were tested. Test results indicate that the width of the sill plate, the size and thickness of the washer, and the magnitude of the eccentricity influence the performance of the sill plate. Minor eccentricities, up to 1-inch for 2 x 4 sill plates and 1-1/2-inches for 2 x 6 sill plates, did not appear to influence the performance of the sill plate. The performance of a 2 x 4 sill plate with 1-inch eccentric anchor bolts was improved when a 3-inch square by 1/2-inch thick slotted plate washer was used. One-half inch diameter bolts that were located 3/4-inch from the edge of the sill, which is the minimum edge distance allowed by the 1991 National Design Standard, performed the poorest.

The location of the first anchor bolt from the end of the shearwall was also considered a test variable. The first anchor bolt was located either 8-inches or 20-inches from the end of the wall. The performance of the sill plate-to-foundation anchorages did not appear to be significantly
influenced by the location of the first anchor bolt. Washer size and thickness described above were more influential.

As discussed in the *Sill Plate Anchorage Mechanics* section of this report, uplift forces at the ends of the shearwall cause the end studs or posts to separate from the sill plate, the sill plate to lift off the foundation, and the sill plate to bend and twist. The deformations associated with these components are influenced by the location of the first anchor bolt. If the first bolt is located close to the end of the wall, deformations associated with the end studs or posts separating from the sill plate dominate over other deformation. Similarly, if the first bolt is located 20-inches from the end of the wall, deformations associated with the sill plate lifting off the foundation, and sill plate bending and twisting dominate.

**Oversize Bolt Holes and Epoxy for Oversized Bolt Holes**

Test results for specimens with 1/8-inch and 1/4-inch diameter oversized anchor bolt holes drilled in the sill plates, and for specimens with oversized anchor bolt holes filled with epoxy indicate that the performance is not influenced by the oversized holes, or the epoxy. The performance level of 2 x 4 sill plates with oversized anchor bolt holes and those with oversized anchor bolt holes filled with epoxy were similar to 2 x 4 sill plates with the same size anchor bolts and washers.

**Slanted Bolts**

Slanted anchor bolt tests used standard round washers. The performance of the specimens appeared to be influenced more by washer and sill plate width than by the installation of the anchor bolts at an angle. Further research and testing is required in this area.

**Power-Driven Pins**

With respect to the power-driven pins, the performance was marginally improved when dead loads were increased, and when larger diameter pins were used to fasten the sill plate to the concrete. The ultimate capacity of the assembly was governed by the pullout capacity of the power-driven pins and the tensile capacity of the concrete. Compared to anchor bolts, the power-driven pins did not perform very well. The maximum number of primary cycles that the power-driven pins were able to achieve was two, compared to the minimum number of primary cycles (5) that the anchor bolts within Group 1 were able to achieve. Power-driven pin performance was limited due to spalling of the concrete at the pins. Further research and testing is required to determine if additional pin embedment and/or the addition of holdowns would substantially improve the performance.

**Special Sill Plate-to-Foundation Connections**

A series of tests were designed in which smooth rods were used instead of anchor bolts with nuts. This was to allow the sill plate to uplift by sliding along the rods without being restrained by the anchor nuts so that the rods would resist only horizontal shear forces. These tests also included holdowns to resist the uplift. Due to sill plate failures in this series of tests, and considering other shearwall assemblies where sill plates did not split, the performance was considered not improved when rods were used in lieu of anchor bolts with nuts and washers.
In another series of tests, a 2 x 4 stud wall was framed onto a 2 x 6 sill plate. The sill plate was bolted to the simulated foundation with 5/8-inch diameter anchor bolts, nuts and standard washers. Blocking was installed between studs and nailed to the 2 x 6 sill plate. Holes were drilled in the blocking to prevent the projecting anchor bolt and nuts from contacting the blocking. Plywood was nailed to the stud framing and into the blocking. The plywood was not nailed to the 2 x 6 sill plate. When 2-inch nominal blocking was used, the blocking split. However, when 3-inch nominal blocking was used, the ultimate load on the shearwall was reached when plywood nails pulled out of the blocking or pulled through the plywood. The 3-inch nominal blocking was considered an improvement over the 2-inch nominal blocking that split during the tests.
Conclusions

The tests conducted under Task 1.4.1.1 have confirmed that the sill plate anchorage of shearwalls is influenced by the uplift of the end of the sill plate. When the shearwall resists lateral forces, an overturning force also develops that causes the sill plates to lift up at the ends of the wall, and causes bending stresses in the sill plate. There is also an inherent eccentricity present in the sill plate due to the sheathing material being nailed to the side of the sill plate and the anchor bolt being located near the center of the sill plate. These two effects can cause bending and cross-grain bending to occur in the sill plate, which may lead to premature brittle splitting.

The objective of this testing program was to improve the understanding of the factors that affect the performance of the sill plate anchorage connections. As presented above in the Test Results section, for purposes of evaluating different test variables and performance levels, the test results were placed into one of four groups. For the first two groups of tests, a test setup was used that loaded the sill plate predominantly with horizontal forces with very little eccentricity. For this test setup, horizontal loads were applied 12-inches above the sill plate of a 4-foot long specimen, which was attached to a simulated foundation with either anchor bolts or power-driven pins.

For the second two groups of tests, a test setup was used that loaded the sill plate with both horizontal forces and vertical forces induced by overturning uplift. For this test setup, loads were applied 96-inches above the sill plate of an 8-foot long specimen, which was attached to a simulated foundation with anchor bolts. Group 4 specimens utilized holdowns to provide resistance to the uplift forces Group 3 specimens did not.

Based on the test results, regardless of the sill plate-to-foundation connection, the height-to-width ratio of the test specimen and the use of holdowns influenced the ultimate strength of the specimen. Specimens with a 1 to 4 ratio (Group 1) had a higher average strength compared to specimens with a 1 to 1 ratio (Group 3), 1723 plf vs. 408 plf. Similarly, specimens with holdowns had a higher average strength compared to specimens without holdowns, 1210 plf for Group 4 vs. 408 plf for Group 3. It is clear from the test results that overturning related forces that cause the sill plate to lift up significantly influence the performance of shearwalls and sill plate-to-foundation connections. When shear forces dominate the forces in sill plate-to-foundation connections, the sill plates do not split and the ultimate strength of the assembly is controlled by components other than the sill plate capacity.

The test variables that significantly influence the performance of sill plate-to-foundation anchorages of shearwalls are washer width and thickness, and holdown strength and stiffness. Sill plate thickness also influences sill plate-to-foundation performance. Washers should be approximately the same width as the sill plate and of adequate thickness to prevent yielding. The washers tend to minimize cross grain bending in the sill plate. Holdowns play an important role in the performance of shearwalls. Holdowns should be strong enough to sustain high cyclic loads, and stiff enough to minimize sill plate uplift and bending.

To further improve the performance of shearwalls, 3-inch nominal sill plates can be used in lieu of 2-inch nominal sill plates due to the additional cross grain bending strength of the 3-inch nominal sill plates. The test results indicate that plate washers can also improve the behavior of the sill plate. Thicker plate washers increase the stiffness of the assembly to resist the cross-grain bending caused by the eccentricity and uplift forces on the wall. Shearwalls with 2-inch
nominal sill plates with washers that extended the full width of the sill plate, and holdowns perform well. Similarly, shearwalls with 3-inch nominal sill plates with 2-1/2-inch square by 1/4-inch thick washers, and holdowns also perform well. With these wall assemblies, the ultimate capacity is reached before the sill plates split.

Wood species, concrete strength, bolt diameter, dead load, oversized bolt holes, epoxy filled oversized bolt holes, distance from end of wall to first bolt, slanted bolts, and sill plate width play a less significant role in the performance of sill plate-to-foundation anchorages. Power-driven pins performed poorly in the tests due to pullout of the pins.

Special sill plate-to-foundation connections that use 3-inch nominal blocks between studs to transfer shear forces from the plywood sheathing to the sill plates performed well. The ultimate capacity of the shearwall with 3-inch nominal blocks is reached before the 3-inch nominal blocks or sill plate split.

In general, the results of the tests demonstrate that if bending and twisting of the sill plate can be limited, the sill plate does not split. If sill plate splitting does not occur, the critical mode of failure of the assembly is not associated with the sill plate-to-foundation connection. With sill plate bending and twisting limited, anchor bolts bend and yield similar to NDS Mode IIIs as long as adequate bolt end and edge distances are provided. The tests also suggest that anchor bolt diameter does not seem to influence the ultimate capacity of the assembly.

Framing members such as end posts and studs at plywood joints should be of adequate strength to avoid splitting failures. When the weak links in the shearwall assembly are strengthened or protected, the ultimate capacity of the shearwall should be based on the capacity of the plywood nails into the framing and through the plywood.
Tentative Recommendations

Based on the results of these tests, some tentative recommendations can be made for the design and construction of shearwalls. These recommendations are intended to produce shearwalls that have more reliable and ductile behavior. Shearwalls that do not incorporate these recommendations may experience brittle failure of the sill plate anchorage. Walls not incorporating these recommendations could be used with the understanding that brittle failures may occur at lower force levels than suggested by the test results and tentative recommendations.

Recommendations for all assemblies:

- End studs should be 4-inch nominal posts. Double studs should not be used as a substitute for 4-inch nominal material. Holdowns should be strong enough to carry large cyclic loads and stiff enough to limit sill plate uplift. Test results suggest that sill plates tend to split when the end of the sill plate was bent upward greater than 3/8-inch and twisted greater than 0.1 radians. This information should be considered tentative and only used as a reference. The attachment of the holdown to the end post should not cause the end post to split.

- At plywood panel joints, 2-inch nominal framing is not of sufficient strength to prevent the stud from splitting. While 4-inch nominal framing used in these tests was of adequate strength, 3-inch nominal framing may also be adequate. Further testing with 3-inch nominal framing is recommended.

Recommendations for Assembly 1: Shearwalls with 2-inch nominal sill plates:

- Full width washers should be located within 20-inches and preferably 8-inches from the end of the wall. The washers can be 3-inches square by 3/8-inch thick in 2 x 4 stud walls, and 5-inches square by 1/2-inch thick in 2 x 6 stud walls. The washers should be diagonally slotted to accommodate construction tolerances.

Recommendations for Assembly 2: Shearwalls with 3-inch nominal sill plates:

- Washers, 2-1/2-inches square by 1/4-inch thick should be located within 20-inches and preferably 8-inches from the end of the wall.

Recommendations for Assembly 3: Special sill plate-to-foundations:

- Blocking should be made of 3-inch nominal material. The blocking should be nailed to the sill plate with 20d nails.
- Plywood should be nailed to the blocking and not the sill plate.

Due to the number of variables being evaluated, the number of tests conducted under this program was not sufficient to develop statistically valid design values. The tests from this task have identified a number of factors that appear to significantly affect shearwall performance. Further research and testing is recommended in the following areas to refine the design of the shearwall assemblies:
• The species of wood used for the sill plates did not appear to provide a significant difference in the performance of the assembly. Due to the limited number of tests performed with similar configurations and varying only wood species, it is difficult to draw any meaningful conclusions based on wood species alone. Additional testing and research is recommended to determine the significance that sill plate species has on sill plate performance.

• The width and thickness of the plate washers affect the performance of the sill plate anchorage. Thick plate washers that extend the full width of the sill plate tend to improve sill plate performance. Additional testing and research is recommended to determine the appropriate width and thickness of plate washers for different sill plate sizes and to determine whether some or all of the anchor bolts need to have special plate washers.

• Tests were conducted with slanted 5/8-inch anchor bolts and standard round washers. The performance of the sill plates with the slanted anchor bolts and standard washers was similar to other tests with anchor bolts installed vertically and standard washers. It appears that washer size has a greater influence on sill plate performance than whether or not the anchor bolts are installed at an angle. Additional testing and research is recommended to determine the affect of washer type and size on sill plates with anchor bolts installed at various angles.

• Height-to-width ratio of shearwalls and applied dead load affect the performance of shearwalls. Walls with low height-to-width ratios and walls with higher applied dead loads tend to uplift less, which improves their behavior. Additional research and testing is recommended that evaluate the performance of shearwalls with different height-to-width ratios and dead load.

• The walls tested in this task were isolated wall elements. The behavior of shearwalls within a building can be influenced by other building elements. Additional research and testing is recommended to determine the affect that other building elements have on the behavior and performance of shearwalls within buildings. Other building elements may include floor assemblies adjacent to shearwalls and/or walls framed into the sides of shearwalls.

• The lateral load applied to the wall assemblies tested under this task used a pin-type connection attached to the top-middle of the specimen. Other tests have used a steel beam attached along the length of the specimen to apply loads to the wall assembly. Further research and testing is recommended to assess the influence that the loading apparatus may have on the behavior of the shearwall.

• For special sill plate-to-foundations, where double 2-inch nominal sill plates are internailed similar to Tests 47, and 48, further testing may demonstrate that this assembly is also adequate.

• Bending and twisting of sill plates are coupled due to the inherent eccentricities between the plywood sheathing and the anchor bolts. The magnitude of the bending or twisting is a function of many of the test variables considered in Task 1.4.1.1. Additional research is required to determine the torsional mechanical properties of sill plates, and to develop design equations for combined bending and twisting of sawn timber.
The walls tested were sheathed with plywood on one side. Shearwalls with plywood sheathing on both sides of the wall may reduce the twisting of the sill plate. Additional research and testing is recommended to evaluate the effects of double-sided sheathing on sill plate performance.
### Appendix 1:
#### Test Setup Matrix

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Wood Species</th>
<th>Nominal Sill Plate Size</th>
<th>Bolt Diameter (inches)</th>
<th>Nut/Washer</th>
<th>Vertical Load</th>
<th>Lateral Loading Notes</th>
<th>Notes</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>1/2</td>
<td>Std. Nut &amp; Cut Washer</td>
<td>100 lb/ft</td>
<td>Horizontal load applied one foot above sill</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>1/2</td>
<td>Std. Nut &amp; Cut Washer</td>
<td>376 lb/ft</td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td>Hem Fir</td>
<td>2 x 6</td>
<td>1/2</td>
<td>Std. Nut &amp; Cut Washer</td>
<td>700 lb/ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8</td>
<td>Std. Nut &amp; Cut Washer</td>
<td>100 lb/ft</td>
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<td></td>
</tr>
<tr>
<td>5</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8</td>
<td>Std. Nut &amp; Cut Washer</td>
<td>376 lb/ft</td>
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<td></td>
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<tr>
<td>6</td>
<td>Hem Fir</td>
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<td>5/8</td>
<td>Std. Nut &amp; Cut Washer</td>
<td>100 lb/ft</td>
<td></td>
<td></td>
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<tr>
<td>7</td>
<td>Douglas Fir</td>
<td>2 x 4</td>
<td>1/2</td>
<td>Std. Nut &amp; Cut Washer</td>
<td>100 lb/ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Douglas Fir</td>
<td>2 x 4</td>
<td>1/2</td>
<td>Std. Nut &amp; Cut Washer</td>
<td>376 lb/ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Douglas Fir</td>
<td>2 x 6</td>
<td>1/2</td>
<td>Std. Nut &amp; Cut Washer</td>
<td>700 lb/ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Southern Pine</td>
<td>2 x 4</td>
<td>1/2</td>
<td>Std. Nut &amp; Cut Washer</td>
<td>100 lb/ft</td>
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<td></td>
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<tr>
<td>10x-100</td>
<td>Southern Pine</td>
<td>2 x 4</td>
<td>1/2</td>
<td>Full plate-width washer and nut</td>
<td>100 lb/ft</td>
<td>2-1/2-inch square by 1/4-inch plate washer</td>
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<tr>
<td>11x-100</td>
<td>Southern Pine</td>
<td>2 x 6</td>
<td>1/2</td>
<td>Full plate-width washer and nut</td>
<td>100 lb/ft</td>
<td>2-1/2-inch square by 1/4-inch plate washer</td>
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<tr>
<td>11-100</td>
<td>Southern Pine</td>
<td>2 x 6</td>
<td>1/2</td>
<td>Std. Nut &amp; Cut Washer</td>
<td>100 lb/ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11-700</td>
<td>Southern Pine</td>
<td>2 x 6</td>
<td>1/2</td>
<td>Std. Nut &amp; Cut Washer</td>
<td>700 lb/ft</td>
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<td></td>
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<tr>
<td>12</td>
<td>Douglas Fir</td>
<td>3 x 4</td>
<td>5/8</td>
<td>Std. Nut &amp; Cut Washer</td>
<td>100 lb/ft</td>
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<td></td>
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<tr>
<td>13m Trial</td>
<td>Douglas Fir</td>
<td>3 x 6</td>
<td>5/8</td>
<td>Std. Nut &amp; Cut Washer</td>
<td>134 lb/ft</td>
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<tr>
<td>13m-2a, 2b</td>
<td>Douglas Fir</td>
<td>3 x 6</td>
<td>5/8</td>
<td>Std. Nut &amp; Cut Washer</td>
<td>134 lb/ft</td>
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<tr>
<td>13m-2c</td>
<td>Douglas Fir</td>
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<td>5/8</td>
<td>Std. Nut &amp; Cut Washer</td>
<td>134 lb/ft</td>
<td></td>
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<tr>
<td>13</td>
<td>Douglas Fir</td>
<td>3 x 6</td>
<td>5/8</td>
<td>Std. Nut &amp; Cut Washer</td>
<td>100 lb/ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13-2</td>
<td>Douglas Fir</td>
<td>3 x 6</td>
<td>5/8</td>
<td>Std. Nut &amp; Cut Washer</td>
<td>100 lb/ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Hem Fir, See note below</td>
<td>2 x 4</td>
<td>0.145</td>
<td>Power-driven pins @ 16&quot; o.c. with standard washer (3 pins total per test specimen)</td>
<td>100 lb/ft</td>
<td></td>
<td>Test specimen: 4 feet wide by 8 feet tall, see note below</td>
</tr>
<tr>
<td>15</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>0.145</td>
<td>Power-driven pins @ 16&quot; o.c. with standard washer (3 pins total per test specimen)</td>
<td>100 lb/ft</td>
<td></td>
<td>Vertical Loads: Use weights suspended from wall</td>
</tr>
<tr>
<td>16</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>0.145</td>
<td>Power-driven pins @ 16&quot; o.c. with standard washer (3 pins total per test specimen)</td>
<td>376 lb/ft</td>
<td></td>
<td>Horizontal loading: Locate bracket 12-inches from sill for all tests</td>
</tr>
<tr>
<td>17</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>0.17</td>
<td>Power-driven pins @ 16&quot; o.c. with standard washer (3 pins total per test specimen)</td>
<td>376 lb/ft</td>
<td></td>
<td>Sill grade: select sills with a variety of grain pattern</td>
</tr>
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</table>
Appendix 1 (continued):
Test Setup Matrix

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Wood Species</th>
<th>Nominal Sill Plate Size</th>
<th>Bolt Diameter (inches)</th>
<th>Nut/Washer</th>
<th>Vertical Load</th>
<th>Lateral Loading Notes</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>Hem Fir, See note below</td>
<td>2 x 4</td>
<td>5/8</td>
<td>Smooth rod w/ no nut or washer</td>
<td>100 lb/ft</td>
<td>Simpson HTT22 Holdown, First anchor bolt 20-inches from end</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Hem Fir, See note below</td>
<td>2 x 4</td>
<td>5/8</td>
<td>Smooth rod w/ no nut or washer</td>
<td>100 lb/ft</td>
<td>Simpson PHD5 Holdown, First anchor bolt 8-inches from end</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Hem Fir, See note below</td>
<td>2 x 4</td>
<td>5/8</td>
<td>Plate washer and nut</td>
<td>100 lb/ft</td>
<td>2x2x3/16 Washer</td>
<td>Horizontal load applied at top of wall</td>
</tr>
<tr>
<td>21</td>
<td>Hem Fir, See note below</td>
<td>2 x 4</td>
<td>5/8</td>
<td>Full plate-width washer and nut</td>
<td>100 lb/ft</td>
<td>Simpson HTT22 Holdown, First anchor bolt 8-inch from end</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Hem Fir, See note below</td>
<td>2 x 6</td>
<td>5/8</td>
<td>Smooth rod w/ no nut or washer</td>
<td>100 lb/ft</td>
<td>Simpson HTT22 Holdown, First anchor bolt 8-inch from end</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Hem Fir, See note below</td>
<td>2 x 6</td>
<td>5/8</td>
<td>Threaded rod w/ no nut or washer</td>
<td>100 lb/ft</td>
<td>2x2x3/16 Washer</td>
<td>Horizontal load applied at top of wall</td>
</tr>
<tr>
<td>24</td>
<td>Hem Fir, See note below</td>
<td>2 x 6</td>
<td>5/8</td>
<td>Plate washer and nut</td>
<td>100 lb/ft</td>
<td>1/8-inch oversize holes</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Hem Fir, See note below</td>
<td>2 x 6</td>
<td>5/8</td>
<td>Full plate-width washer and nut</td>
<td>100 lb/ft</td>
<td>1/8-inch oversize holes w/ epoxy</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Hem Fir, See note below</td>
<td>2 x 4</td>
<td>5/8</td>
<td>Full plate-width washer and nut</td>
<td>100 lb/ft</td>
<td>Slanted bolt</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Hem Fir, See note below</td>
<td>2 x 4</td>
<td>5/8</td>
<td>Full plate-width washer and nut</td>
<td>100 lb/ft</td>
<td>1/4-inch oversize holes</td>
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</tr>
<tr>
<td>28</td>
<td>Hem Fir, See note below</td>
<td>2 x 4</td>
<td>5/8</td>
<td>Standard nut &amp; beveled plate washer</td>
<td>100 lb/ft</td>
<td>1/4-inch oversize holes w/ epoxy</td>
<td></td>
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<tr>
<td>29</td>
<td>Hem Fir, See note below</td>
<td>2 x 4</td>
<td>5/8</td>
<td>Full plate-width washer and nut</td>
<td>100 lb/ft</td>
<td>Slanted bolt</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Hem Fir, See note below</td>
<td>2 x 4</td>
<td>5/8</td>
<td>Full plate-width washer and nut</td>
<td>100 lb/ft</td>
<td>Bolt 2-inch off center, Slot 4-3/4-inch from center</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Hem Fir, See note below</td>
<td>2 x 6</td>
<td>5/8</td>
<td>Full plate-width washer and nut</td>
<td>100 lb/ft</td>
<td>Bolt 1-inch off center, Slot 3-3/4-inch from center</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>Hem Fir, See note below</td>
<td>2 x 4</td>
<td>5/8</td>
<td>Simpson LBPS 5/8 washer &amp; nut</td>
<td>100 lb/ft</td>
<td>Bolt 2-inches off center, Slot 4-1/4-inches from center</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Hem Fir, See note below</td>
<td>2 x 4</td>
<td>5/8</td>
<td>1/2&quot; Slotted Plate washer and nut</td>
<td>100 lb/ft</td>
<td>Bolt 1-inches off center, Slot 3-1/4-inches from center</td>
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<tr>
<td>34</td>
<td>Hem Fir, See note below</td>
<td>2 x 6</td>
<td>1/2</td>
<td>Simpson LBPS 5/8 washer &amp; nut</td>
<td>100 lb/ft</td>
<td>Bolt 1-1/2--inches off center, Slot 4-1/4-inches from center</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Hem Fir, See note below</td>
<td>2 x 6</td>
<td>5/8</td>
<td>Simpson LBPS 5/8 washer &amp; nut</td>
<td>100 lb/ft</td>
<td>Bolt 2-1/2--inches off center, Slot 4-1/4-inches from center</td>
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</tr>
<tr>
<td>36</td>
<td>Hem Fir, See note below</td>
<td>2 x 6</td>
<td>5/8</td>
<td>Simpson LBPS 5/8 washer &amp; nut</td>
<td>100 lb/ft</td>
<td>Bolt 1-inch off center, Slot 3-3/4-inch from center</td>
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</tbody>
</table>
### Appendix 1 (continued):
#### Test Setup Matrix

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Wood Species</th>
<th>Nominal Sill Plate Size</th>
<th>Bolt Diameter (inches)</th>
<th>Nut/Washer</th>
<th>Vertical Load</th>
<th>Lateral Loading Notes</th>
<th>Notes</th>
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</thead>
<tbody>
<tr>
<td>37</td>
<td>Douglas Fir</td>
<td>3 x 4</td>
<td>5/8</td>
<td>Full plate-width washer and nut</td>
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<td>Holdown at end stud - PHD5, First anchor bolt 8-inches from end</td>
<td>2x Douglas Fir to compare 3x Douglas Fir test</td>
</tr>
<tr>
<td>38x</td>
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<td>2 x 4</td>
<td>5/8</td>
<td>Full plate-width washer and nut</td>
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<td>3x sills: toenail studs to sill per UBC</td>
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<tr>
<td>38</td>
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<td>3 x 4</td>
<td>5/8</td>
<td>Full plate-width washer and nut</td>
<td></td>
<td>Holdown at end stud - HTT22, First anchor bolt 8-inches from end</td>
<td>3x sills: toenail studs to sill per UBC; Monotonic Loading for Qo</td>
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<tr>
<td>39</td>
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<td>3 x 6</td>
<td>5/8</td>
<td>Full plate-width washer and nut</td>
<td></td>
<td>Holdown at end stud - HTT22, First anchor bolt 8-inches from end</td>
<td>2x Douglas Fir to compare 3x Douglas Fir test</td>
</tr>
<tr>
<td>40m</td>
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<td>Full plate-width washer and nut</td>
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<td>Holdown at end stud - HTT22, First anchor bolt 8-inches from end</td>
<td>3x sills: toenail studs to sill per UBC</td>
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<tr>
<td>40x</td>
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<td>2 x 6</td>
<td>5/8</td>
<td>Full plate-width washer and nut</td>
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<td>Holdown at end stud - PHD5, First anchor bolt 20-inches from end</td>
<td></td>
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<tr>
<td>40</td>
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<td>3 x 6</td>
<td>5/8</td>
<td>Full plate-width washer and nut</td>
<td></td>
<td>Holdown at double end studs - PHD5, First anchor bolt 20-inches from end</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td></td>
<td>2 x 4</td>
<td>5/8</td>
<td>3-in.square by 1/2-in. thick slotted plate</td>
<td>100 lb/ft</td>
<td>Holdown at end stud - PHD5, First anchor bolt 8-inches from end</td>
<td></td>
</tr>
<tr>
<td>41b</td>
<td></td>
<td>2 x 4</td>
<td>5/8</td>
<td>3-in.square by 1/2-in. thick slotted plate</td>
<td></td>
<td>Holdown w/ 4x4 end post - PHD5, First anchor bolt 20-inches from end</td>
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<tr>
<td>41b-4x4.1</td>
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<td>3-in.square by 1/2-in. thick slotted plate</td>
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<td>Holdown w/ 4x4 end post, 2x stud at center - PHD5, First anchor bolt 20-inches from end</td>
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<td>41b-4x4.2</td>
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<td>3-in.square by 1/2-in. thick slotted plate</td>
<td></td>
<td>Holdown w/ 4x4 end post, 4x4 stud at center - PHD5, First anchor bolt 20-inches from end</td>
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<tr>
<td>41b-4x4.3</td>
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<td>2 x 4</td>
<td>5/8</td>
<td>3-in.square by 1/2-in. thick slotted plate</td>
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<td>Holdown at end stud - PHD5, First anchor bolt 20-inches from end</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td></td>
<td>2 x 4</td>
<td>5/8</td>
<td>3-in.square by 1/2-in. thick slotted plate</td>
<td></td>
<td>Holdown at end stud - PHD5, First anchor bolt 20-inches from end</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>Hem Fir, See note below</td>
<td>2 x 4</td>
<td>5/8</td>
<td>Std. Nut &amp; Cut Washer</td>
<td></td>
<td>Holdown at end stud - PHD5, First anchor bolt 20-inches from end</td>
<td></td>
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<tr>
<td>44</td>
<td></td>
<td>2 x 6</td>
<td>5/8</td>
<td>2-inch square by 3/16-inch thick plate</td>
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<td>Holdown at end stud - PHD5, First anchor bolt 20-inches from end</td>
<td></td>
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<tr>
<td>45</td>
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<td>2 x 6</td>
<td>5/8</td>
<td>5-inch square by 1/2-inch thick plate</td>
<td></td>
<td>Holdown at end stud - PHD5, First anchor bolt 20-inches from end</td>
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<tr>
<td>46</td>
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<td>2 x 6</td>
<td>5/8</td>
<td>Std. Nut &amp; Cut Washer</td>
<td></td>
<td>Holdown at end stud - PHD5, First anchor bolt 20-inches from end</td>
<td></td>
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</table>
### Appendix 1 (continued):
**Test Setup Matrix**

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Wood Species</th>
<th>Nominal Sill Plate Size</th>
<th>Bolt Diameter (inches)</th>
<th>Nut/Washer</th>
<th>Vertical Load</th>
<th>Lateral Loading Notes</th>
<th>Notes</th>
</tr>
</thead>
</table>
| 47      | Doug Fir
          | Upper Hem Fir
          | 2 x 4 upper & 2 x 6 lower | 5/8                      | Std. Nut & Cut Washer       | 100 lb/ft     | 10 d COMMON nails @ 3-inches connecting sills, anchor bolt 8-inches from end stud, HTT22 holdown |
| 48      | Doug Fir
          | Upper Hem Fir
          | 2 x 4 upper & 2 x 6 lower | 5/8                      | Std. Nut & Cut Washer       | 100 lb/ft     | 10 d COMMON nails @ 3-inches connecting sills, anchor bolt 8-inches from end stud, HTT22 holdown |
| 49      | Doug Fir
          | Upper Hem Fir
          | 3 x 4 upper & 2 x 6 lower | 5/8                      | Std. Nut & Cut Washer       | 100 lb/ft     | 20d galv. box nails, 40 total (2-1/2-inches o.c.) connecting sills, anchor bolt 8-inches from end stud, PHD5 holdown |
| 50      | Hem Fir, See note below | 2 x 4 | 5/8                      | 3-inch square by 1/2-inch thick slotted plate | 100 lb/ft     | Holdown at end stud - HTT22, First anchor bolt 20-inches from end                           |
| 51      | Hem Fir, See note below | 2 x 4 | 5/8                      | At ends: 3-inch square by 3/16-inch plate washer. At interior: Standard round washer | 100 lb/ft     | Holdown at end stud - PHD5, First anchor bolt 8-inches from end                           |
| 52      | Hem Fir, See note below | 2 x 4 | 5/8                      | At ends: 3-inch square by 1/4-inch plate washer. At interior: Standard round washer | 100 lb/ft     | Holdown at end stud - PHD5, First anchor bolt 8-inches from end                           |

**General Notes:**
1. Standard cut washer = 1-1/2 +/− inch diameter, Oversized plate washer = 2-inch square by 3/16-inch thick, Full plate-width washer = 2-1/2-inch square by 1/4-inch
2. Slotted plate = Simpson LBPS 5/8
3. 3-inch square by 1/2-inch thick plate = Slotted 3-inch square by 1/2-inch thick plate
4. Sill Plates: Selected sill randomly with varying grain and log size.
5. Anchor bolts secured finger tight PLUS 1/4 turn
6. Sills face nailed to studs unless otherwise noted
7. Tests 13m and 40m are monotonic tests to establish cyclic test parameter $Q_o$
8. Tests 13m and 40m use 3 x 6, Pressure-treated Douglas Fir
9. Plywood: Thickness varies see Appendix 2 through 5.
10. Gun Nails for Plywood: Full heads, Not Overdriven
### Appendix 2:
#### Group 1 Test Results

Q₀ = 8,000 lbs

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Wood Species</th>
<th>Nominal Sill Plate Size</th>
<th>Bolt Diameter</th>
<th>Nut/Washer</th>
<th>Dead Load (plf)</th>
<th>Ultimate Load (plf)</th>
<th>Ratio of Q₀</th>
<th># of Primary Cycles</th>
<th>Sill Failure</th>
<th>Plywood Nail Failure</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>1/2</td>
<td>Round</td>
<td>100</td>
<td>1636</td>
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<td>5</td>
<td>X</td>
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<td></td>
</tr>
<tr>
<td>2</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>1/2</td>
<td>Round</td>
<td>376</td>
<td>1612</td>
<td>0.9</td>
<td>6</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Hem Fir</td>
<td>2 x 6</td>
<td>1/2</td>
<td>Round</td>
<td>700</td>
<td>2040</td>
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<td>8</td>
<td>X</td>
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</tr>
<tr>
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<td>2 x 4</td>
<td>5/8</td>
<td>Round</td>
<td>100</td>
<td>1386</td>
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<td>X</td>
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<td>Hem Fir</td>
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<td>5/8</td>
<td>Round</td>
<td>376</td>
<td>1792</td>
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<td>Hem Fir</td>
<td>2 x 6</td>
<td>5/8</td>
<td>Round</td>
<td>100</td>
<td>1638</td>
<td>0.8</td>
<td>5</td>
<td>X</td>
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</tr>
<tr>
<td>7</td>
<td>Douglas Fir</td>
<td>2 x 4</td>
<td>1/2</td>
<td>Round</td>
<td>100</td>
<td>1640</td>
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<td>X</td>
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<td>8</td>
<td>Douglas Fir</td>
<td>2 x 4</td>
<td>1/2</td>
<td>Round</td>
<td>376</td>
<td>1179</td>
<td>0.8</td>
<td>5</td>
<td>X</td>
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</tr>
<tr>
<td>9</td>
<td>Douglas Fir</td>
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<td>1/2</td>
<td>Round</td>
<td>700</td>
<td>2187</td>
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<td>10</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Southern Pine</td>
<td>2 x 4</td>
<td>1/2</td>
<td>Round</td>
<td>100</td>
<td>1629</td>
<td>0.9</td>
<td>6</td>
<td>X</td>
<td></td>
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</tr>
</tbody>
</table>
## Appendix 2 (continued):
**Group 1 Test Results**

$Q_0 = 8,000$ lbs

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Wood Species</th>
<th>Nominal Sill Plate Size</th>
<th>Bolt Diameter</th>
<th>Nut/Washer</th>
<th>Dead Load (plf)</th>
<th>Ultimate Load (plf)</th>
<th>Ratio of $Q_0$</th>
<th># of Primary Cycles</th>
<th>Sill Failure</th>
<th>Plywood Nail Failure</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>10x-100</td>
<td>Southern Pine</td>
<td>2 x 4</td>
<td>1/2</td>
<td>2-1/2-in. sq. by 1/4-in. pl. washer</td>
<td>100</td>
<td>1898</td>
<td>0.9</td>
<td>7</td>
<td>X</td>
<td></td>
<td>1/2-inch plywood, Max load = 7591# (1898 plf)</td>
</tr>
<tr>
<td>11x-100</td>
<td>Southern Pine</td>
<td>2 x 6</td>
<td>1/2</td>
<td>2-1/2-in. sq. by 1/4-in. pl. washer</td>
<td>100</td>
<td>1739</td>
<td>0.9</td>
<td>7</td>
<td>X</td>
<td></td>
<td>1/2-inch plywood, Max load = 6955# (1739 plf)</td>
</tr>
<tr>
<td>11-100</td>
<td>Southern Pine</td>
<td>2 x 6</td>
<td>Round</td>
<td>100</td>
<td>1867</td>
<td>0.9</td>
<td>6</td>
<td>X</td>
<td></td>
<td></td>
<td>1/2-inch plywood, Max load = 7470# (1867 plf)</td>
</tr>
<tr>
<td>11-700</td>
<td>Southern Pine</td>
<td>2 x 6</td>
<td>Round</td>
<td>700</td>
<td>2101</td>
<td>1.0</td>
<td>8</td>
<td>X</td>
<td></td>
<td></td>
<td>1/2-in. plywood, Max load = 8405# (2101 plf)</td>
</tr>
<tr>
<td>12</td>
<td>Douglas Fir</td>
<td>3 x 4</td>
<td>Round</td>
<td>100</td>
<td>1588</td>
<td>0.8</td>
<td>5</td>
<td>X</td>
<td></td>
<td></td>
<td>3/8-inch plywood, Bolts bent, Sill split, Eccentric load applied as specimen uplifted, Revise loading ram</td>
</tr>
<tr>
<td>13m-Trial</td>
<td>Douglas Fir</td>
<td>3 x 6</td>
<td>Round</td>
<td>134</td>
<td></td>
<td>Not reliable data, see Test 13m-2a, 2b</td>
<td>X</td>
<td>Not reliable data, see Test 13m-2a, 2b</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13m-2a, 2b</td>
<td>Douglas Fir</td>
<td>3 x 6</td>
<td>Round</td>
<td>134</td>
<td>1888</td>
<td>--</td>
<td>--</td>
<td>X</td>
<td></td>
<td></td>
<td>3/8-inch plywood, Bolt bent, Load applied concentrically, $Q_o = 7550#$, Use $Q_o = 8,000$#</td>
</tr>
<tr>
<td>13m-2c</td>
<td>Douglas Fir</td>
<td>3 x 6</td>
<td>Round</td>
<td>134</td>
<td>2164</td>
<td>--</td>
<td>--</td>
<td>X</td>
<td></td>
<td></td>
<td>5/8-inch plywood, Bolt bent, Load applied concentrically, Nails pulled out of sill plate, $Q_o = 8654#$, Use $Q_o = 8,000$#</td>
</tr>
<tr>
<td>13</td>
<td>Douglas Fir</td>
<td>3 x 6</td>
<td>Round</td>
<td>100</td>
<td></td>
<td>Not reliable data, see Test 13-2</td>
<td>X</td>
<td>Not reliable data, see Test 13-2</td>
<td></td>
<td>5/8-inch plywood, Specimen failed prematurely in part due to studs not flush with sill plate. Retest, see 13-2</td>
<td></td>
</tr>
</tbody>
</table>
### Appendix 2 (continued):

**Group 1 Test Results**  
\[ Q_0 = 8,000 \text{ lbs} \]

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Wood Species</th>
<th>Nominal Sill Plate Size</th>
<th>Bolt Diameter</th>
<th>Nut/Washer</th>
<th>Dead Load (plf)</th>
<th>Ultimate Load (plf)</th>
<th>Ratio of ( Q_0 )</th>
<th># of Primary Cycles</th>
<th>Sill Failure</th>
<th>Plywood Nail Failure</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>13-2</td>
<td>Douglas Fir</td>
<td>3 x 6</td>
<td>5/8</td>
<td>Round</td>
<td>100</td>
<td>1638</td>
<td>0.8</td>
<td>5</td>
<td>X</td>
<td></td>
<td>1/2-inch plywood, Plywood nails pulled through, Max load = 6552# (1638plf), 5 primary cycles (0.8( Q_0 ))</td>
</tr>
</tbody>
</table>

**General Notes:**
1. \( Q_0 = 8000 \text{ lbs} \).
2. Standard cut washer = 1-1/2 +/- inch diameter, Oversized plate washer = 2-inch square by 3/16-inch thick, Full plate-width washer = 2-1/2-inch square by 1/4-inch
3. Slotted plate = Simpson LBPS 5/8
4. 3-inch square by 1/2-inch thick plate = Slotted 3-inch square by 1/2-inch thick plate
5. Sill Plates: Selected sill randomly with varying grain and log size.
6. Anchor bolts secured finger tight PLUS 1/4 turn
7. Sills face nailed to studs unless otherwise noted
8. Tests 13m and 40m are monotonic tests to establish cyclic test parameter \( Q_0 \)
9. Tests 13m and 40m use 3 x 6, Pressure-treated Douglas Fir
10. Gun Nails for Plywood: Full heads, Not Overdriven
Appendix 2B
Test 10
Load vs. Time History

- Applied Load (lbs.): 1629 plf
  - 82% of $Q_0$
  - $Q_0=8000$ lbs.
Appendix 2B
Test 10C
Load vs. Deflection at Applied Load

**1629 plf**
82% of $Q_0$
$Q_0=8000$ lbs.
Appendix 2B
Test 10
Load vs. Sill Horizontal Displacement at Anchor Bolts

Sill deflection at far end anchor bolt.

Sill deflection at ram end anchor bolt.
Appendix 2B
Test 10
Load vs. Sill Vertical Displacement at Anchor Bolts

Sill deflection at far end anchor bolt.

Sill deflection at ram end anchor bolt.
Appendix 2B
Test 10
Load vs. Plywood Vertical Displacement

Plywood deflection at far end.

Plywood deflection at ram end.
Appendix 2B
Test 10
Load vs. Sill Vertical Displacement Away From Plywood

![Graph showing load vs. sill vertical displacement for Test 10. The x-axis represents vertical deflection in inches, ranging from -0.30 to 0.30. The y-axis represents applied load in pounds, ranging from -10000 to 10000. Several curves are depicted, indicating the deflection behavior under different loads. Arrows point to the sill deflection at the ram end and at the far end.]
Appendix 2C
Test 10X
Load vs. Time History

Applied Load (lbs.)

2055 plf
103% of Q_0
Q_0=8000lbs.
Appendix 2C
Test 10X
Load vs. Deflection at Applied Load

Applied Load (lbs.) vs. Horizontal Deflection (in.)

2055 plf
103% of $Q_0$
$Q_0=8000$ lbs.
Appendix 2C
Test 10X
Load vs. Sill Horizontal Displacement at Anchor Bolts

Horizontal Deflection (in.)

Applied Load (lbs.)

Sill deflection at ram end anchor bolt.

Sill deflection at far end anchor bolt.
Appendix 2C
Test 10X
Load vs. Sill Vertical Displacement at Anchor Bolts

<table>
<thead>
<tr>
<th>Applied Load (lbs.)</th>
<th>Vertical Deflection (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-10000</td>
<td>-0.10</td>
</tr>
<tr>
<td>-8000</td>
<td>-0.08</td>
</tr>
<tr>
<td>-6000</td>
<td>-0.05</td>
</tr>
<tr>
<td>-4000</td>
<td>-0.03</td>
</tr>
<tr>
<td>-2000</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0.03</td>
</tr>
<tr>
<td>2000</td>
<td>0.05</td>
</tr>
<tr>
<td>4000</td>
<td>0.08</td>
</tr>
<tr>
<td>6000</td>
<td>0.10</td>
</tr>
<tr>
<td>8000</td>
<td>-0.10</td>
</tr>
<tr>
<td>10000</td>
<td>-0.08</td>
</tr>
</tbody>
</table>

Sill deflection at ram end.
Sill deflection at far end.
Appendix 2C
Test 10X
Load vs. Plywood Vertical Displacement

Plywood deflection at far end.
Plywood deflection at ram end.
Appendix 2C
Test 10X
Load vs. Sill Vertical Displacement Near Plywood

Sill deflection at far end.

Sill deflection at ram end.
Appendix 2C
Test 10X
Load vs. Sill Vertical Displacement Away From Plywood

Sill deflection at far end
Sill deflection at ram end.
## Appendix 3:
### Group 2 Test Results

**Q₀ = 8,000lbs**

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Wood Species</th>
<th>Nominal Sill Plate Size</th>
<th>Pin Diameter</th>
<th>Nut/Washer</th>
<th>Dead Load (plf)</th>
<th>Ultimate Load (plf)</th>
<th>Ratio of Q₀</th>
<th># of Primary Cycles</th>
<th>Sill Failure</th>
<th>Plywood Nail Failure</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>0.145-inch</td>
<td>Standard Washer</td>
<td>100</td>
<td>809</td>
<td>0.4</td>
<td>1</td>
<td>See Comments</td>
<td>1/2-inch plywood, Pins pulled out of concrete, concrete spalled, washers bent, Max load = 3237# (809plf)</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>0.145-inch</td>
<td>Standard Washer</td>
<td>100</td>
<td>682</td>
<td>0.4</td>
<td>1</td>
<td>See Comments</td>
<td>1/2-inch plywood, Pins pulled out of concrete, concrete spalled, washers bent, Max load = 2728# (682plf)</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>0.145-inch</td>
<td>Standard Washer</td>
<td>376</td>
<td>793</td>
<td>0.4</td>
<td>1</td>
<td>See Comments</td>
<td>1/2-inch plywood, Pins pulled out of concrete, concrete spalled, pin bent, Max load = 3170# (793plf)</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>0.17-inch</td>
<td>Standard Washer</td>
<td>376</td>
<td>974</td>
<td>0.5</td>
<td>2</td>
<td>See Comments</td>
<td>1/2-inch plywood, Pins pulled out of concrete, concrete spalled, washers bent, Max load = 3897# (974plf)</td>
<td></td>
</tr>
</tbody>
</table>

**General Notes:**

1. **Q₀ = 8000 lbs.**
2. Standard cut washer = 1-1/2 +/- inch diameter, Oversized plate washer = 2-inch square by 3/16-inch thick, Full plate-width washer = 2-1/2-inch square by 1/4-inch
3. Slotted plate = Simpson LBPS 5/8
4. 3-inch square by 1/2-inch thick plate = Slotted 3-inch square by 1/2-inch thick plate
5. Sill Plates: Selected sill randomly with varying grain and log size.
6. Anchor bolts secured finger tight PLUS 1/4 turn
7. Sills face nailed to studs unless otherwise noted
8. Gun Nails for Plywood: Full heads, Not Overdriven
Appendix 3B
Test 17
Load vs. Time History

Applied Load (lbs.)

974 plf
49% of $Q_0$
$Q_0=8000$ lbs.
Appendix 3B
Test 17C
Load vs. Deflection at Applied Load

Applied Load (lbs.)

Horizontal Deflection (in.)

-10000 -8000 -6000 -4000 -2000 0 2000 4000 6000 8000 10000

-3.0 -2.5 -2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5

974 plf
49% of Q₀
Q₀=8000lbs

Anchorage of Woodframe Buildings - Laboratory Testing Report
Appendix 3B
Test 17
Load vs. Sill Horizontal Displacement at Anchor Bolts

Sill deflection at ram end anchor

Sill deflection at far end anchor bolt.
Appendix 3B
Test 17
Load vs. Sill Vertical Displacement at Anchor Bolts

Sill deflection at ram end.

Sill deflection at far end.
Appendix 3B
Test 17
Load vs. Plywood Vertical Displacement

Plywood deflection at far end.

Plywood deflection at ram end.
Appendix 3B
Test 17
Load vs. Sill Vertical Displacement Near Plywood

Sill deflection at far end.

Sill deflection at ram end.

Applied Load (lbs.)

Vertical Deflection (in.)
Appendix 3B
Test 17
Load vs. Sill Vertical Displacement Away From Plywood

- Applied Load (lbs.)
- Vertical Deflection (in.)

Sill deflection at ram end.
Sill deflection at far end.
Appendix 4: 
Group 3 (w/o Holdowns) Test Results 
$Q_0 = 3,200\text{lbs}$

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Wood Species</th>
<th>Nominal Sill Plate Size</th>
<th>Bolt Diameter</th>
<th>Nut/Washer</th>
<th>Dead Load (plf)</th>
<th>Ultimate Load (plf)</th>
<th>Ratio of $Q_0$</th>
<th># of Primary Cycles</th>
<th>Sill Failure</th>
<th>Plywood Nail Failure</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8</td>
<td>2-in. sq. by 3/16-in. plate washer</td>
<td>100</td>
<td>391</td>
<td>1.0</td>
<td>9</td>
<td>X</td>
<td></td>
<td>1/2-inch plywood, Max load = 3128# (391 plf)</td>
</tr>
<tr>
<td>21</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8</td>
<td>2-1/2-in. sq. by 1/4-in. plate washer</td>
<td>100</td>
<td>480</td>
<td>1.2</td>
<td>12</td>
<td>X</td>
<td></td>
<td>1/2-inch plywood, Max load = 3840# (480 plf)</td>
</tr>
<tr>
<td>24</td>
<td>Hem Fir</td>
<td>2 x 6</td>
<td>5/8</td>
<td>2-in. sq by 3/16-in. plate washer</td>
<td>100</td>
<td>370</td>
<td>1.0</td>
<td>8</td>
<td>X</td>
<td></td>
<td>1/2-inch plywood, Max load = 2957# (370 plf)</td>
</tr>
<tr>
<td>25</td>
<td>Hem Fir</td>
<td>2 x 6</td>
<td>5/8</td>
<td>2-1/2-in. sq. by 1/4-in. plate washer</td>
<td>100</td>
<td>336</td>
<td>0.9</td>
<td>7</td>
<td>X</td>
<td></td>
<td>1/2-inch plywood, Max load = 2688# (336 plf)</td>
</tr>
<tr>
<td>26</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8</td>
<td>2-1/2-in. sq. by 1/4-in. plate washer</td>
<td>100</td>
<td>437</td>
<td>1.1</td>
<td>10</td>
<td>X</td>
<td></td>
<td>1/8-inch oversize holes, 1/2-inch plywood, Max load = 3496# (437 plf)</td>
</tr>
<tr>
<td>27</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8</td>
<td>2-1/2-in. sq. by 1/4-in. plate washer</td>
<td>100</td>
<td>425</td>
<td>1.1</td>
<td>10</td>
<td>X</td>
<td></td>
<td>1/8-inch oversize holes w/ epoxy, 1/2-inch plywood, Max load = 3401# (425 plf)</td>
</tr>
</tbody>
</table>
### Appendix 4(continued):
Group 3 (w/o Holdowns) Test Results

\[ Q_0 = 3,200\text{lbs} \]

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Wood Species</th>
<th>Nominal Sill Plate Size</th>
<th>Bolt Diameter</th>
<th>Nut/Washer</th>
<th>Dead Load (plf)</th>
<th>Ultimate Load (plf)</th>
<th>Ratio of ( Q_0 )</th>
<th># of Primary Cycles</th>
<th>Sill Failure</th>
<th>Plywood Nail Failure</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8</td>
<td>Round</td>
<td>100</td>
<td>352</td>
<td>0.9</td>
<td>6</td>
<td>X</td>
<td></td>
<td>Slanted bolt, 1/2-inch plywood, Max load = 2819# (352 plf)</td>
</tr>
<tr>
<td>29</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8</td>
<td>2-1/2 in. sq. by 1/4 in. plate washer</td>
<td>100</td>
<td>482</td>
<td>1.2</td>
<td>12</td>
<td>X</td>
<td>1/4-inch oversize holes, 1/2-inch plywood, Max load = 3857# (482 plf)</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8</td>
<td>2-1/2 in. sq. by 1/4 in. plate washer</td>
<td>100</td>
<td>464</td>
<td>1.2</td>
<td>12</td>
<td>X</td>
<td>1/4-inch oversize holes w/ epoxy, 1/2-inch plywood, Max load = 3715# (464 plf)</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Hem Fir</td>
<td>2 x 6</td>
<td>5/8</td>
<td>Round</td>
<td>100</td>
<td>282</td>
<td>0.8</td>
<td>5</td>
<td>X</td>
<td>Slanted bolt, 1/2-inch plywood, Max load = 2254# (282 plf)</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8</td>
<td>Simpson LBPS 5/8</td>
<td>100</td>
<td>371</td>
<td>1.0</td>
<td>8</td>
<td>X</td>
<td>Bolt 1/2-inch off center, 1/2-inch plywood, Sill plate split at anchor bolt center line, washer bent, Max load = 2970# (371 plf)</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8</td>
<td>3 in. sq. by 1/2 in. slotted plate</td>
<td>100</td>
<td>403</td>
<td>1.0</td>
<td>9</td>
<td>X</td>
<td>Bolt 1-inch off center, 1/2-inch plywood, Sill plate split and broke, Max load = 3221# (403 plf)</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Hem Fir</td>
<td>2 x 6</td>
<td>1/2</td>
<td>Simpson LBPS 5/8</td>
<td>100</td>
<td>240</td>
<td>0.6</td>
<td>3</td>
<td>X</td>
<td>Bolt 2-inches off center, 1/2-inch plywood, washer bent, Max load = 1923# (240 plf)</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Hem Fir</td>
<td>2 x 6</td>
<td>5/8</td>
<td>Simpson LBPS 5/8</td>
<td>100</td>
<td>320</td>
<td>0.8</td>
<td>5</td>
<td>X</td>
<td>Bolt 1-inch off center, 1/2-inch plywood, washer bent, Max load = 2563# (320 plf)</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>Hem Fir</td>
<td>2 x 6</td>
<td>5/8</td>
<td>Simpson LBPS 5/8</td>
<td>100</td>
<td>325</td>
<td>0.8</td>
<td>5</td>
<td>X</td>
<td>Bolt 1-1/2-inches off center, 1/2-inch plywood, washer bent, Max load = 2600# (325 plf)</td>
<td></td>
</tr>
</tbody>
</table>
### Appendix 4(continued):
#### Group 3 (w/o Holdowns) Test Results

**Q₀ = 3,200lbs**

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Wood Species</th>
<th>Nominal Sill Plate Size</th>
<th>Bolt Diameter</th>
<th>Nut/ Washer</th>
<th>Dead Load (plf)</th>
<th>Ultimate Load (plf)</th>
<th>Ratio of Q₀</th>
<th># of Primary Cycles</th>
<th>Sill Failure</th>
<th>Plywood Nail Failure</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>38x</td>
<td>Douglas Fir</td>
<td>2 x 4</td>
<td>5/8</td>
<td>2-1/2 in. Sq. by 1/4 in. pl. washer</td>
<td>100</td>
<td>433</td>
<td>1.1</td>
<td>11</td>
<td>X</td>
<td>1/2-inch plywood, Sill plate split and broke, Max load = 3464# (433 plf)</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>Douglas Fir</td>
<td>3 x 4</td>
<td>5/8</td>
<td>2-1/2 in. Sq. by 1/4 in. pl. washer</td>
<td>100</td>
<td>645</td>
<td>1.8</td>
<td>20</td>
<td>X</td>
<td>1/2-inch plywood, Max load = 5157# (645 plf)</td>
<td></td>
</tr>
<tr>
<td>40m</td>
<td>Douglas Fir</td>
<td>3 x 6</td>
<td>5/8</td>
<td>2-1/2 in. Sq. by 1/4 in. pl. washer</td>
<td>100</td>
<td>487</td>
<td>N/A</td>
<td>N/A</td>
<td>X</td>
<td>1/2-inch plywood, Max load = 3892#. Establish Q₀ = 3200#</td>
<td></td>
</tr>
<tr>
<td>40x</td>
<td>Douglas Fir</td>
<td>2 x 6</td>
<td>5/8</td>
<td>2-1/2 in. sq. by 1/4 in. plate washer</td>
<td>100</td>
<td>384</td>
<td>1.0</td>
<td>8</td>
<td>X</td>
<td>1/2-inch plywood, Sill plate split, Max load = 3074# (384 plf)</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Douglas Fir</td>
<td>3 x 6</td>
<td>5/8</td>
<td>2-1/2 in. sq. by 1/4 in. plate washer</td>
<td>100</td>
<td>530</td>
<td>1.3</td>
<td>15</td>
<td>X</td>
<td>1/2-inch plywood, Max load = 4236# (530 plf)</td>
<td></td>
</tr>
</tbody>
</table>

**General Notes:**
1. Q₀ = 3200 lbs.
2. Standard cut washer = 1-1/2 +/- inch diameter, Oversized plate washer = 2-inch square by 3/16-inch thick, Full plate-width washer = 2-1/2-inch square by 1/4-inch
3. Slotted plate = Simpson LBPS 5/8
4. 3-inch square by 1/2-inch thick plate = Slotted 3-inch square by 1/2-inch thick plate
5. Sill Plates: Selected sill randomly with varying grain and log size.
6. Anchor bolts secured finger tight PLUS 1/4 turn
7. Sills face nailed to studs unless otherwise noted
8. Tests 13m and 40m are monotonic tests to establish cyclic test parameter Q₀
9. Tests 13m and 40m use 3 x 6, Pressure-treated Douglas Fir
10. Gun Nails for Plywood: Full heads, Not Overdriven
Appendix 4B
Test 21C
Load vs. Time History

Applied Load (lbs.):
-4000 -3000 -2000 -1000 0 1000 2000 3000 4000

Time (hh:mm:ss):

480 plf
120% of Q₀
Q₀=3200 lbs.
Appendix 4B
Test 21C
Load vs. Deflection at Top of Wall

Applied Load (lbs.) vs. Horizontal Deflection (in.)

-4000  -3000  -2000  -1000  0  1000  2000  3000  4000

-5.0  -4.0  -3.0  -2.0  -1.0  0.0  1.0  2.0  3.0  4.0  5.0

480 plf
120% of Q₀
Q₀ = 3200 lbs.
Appendix 4B
Test 21C
Load vs. Sill Vertical Displacement at Anchor Bolts

Applied Load (lbs.) vs. Sill Deflection (in.)

- Sill deflection at ram end anchor bolt.
- Sill deflection at first interior anchor bolt.
- Sill deflection at second interior anchor bolt.
- Sill deflection at far end anchor bolt.
Appendix 4B
Test 21C
Load vs. Sill Horizontal Displacement at Anchor Bolts

- Sill deflection at first interior anchor bolt.
- Sill deflection at ram end anchor bolt.
- Sill deflection at second interior anchor bolt.
- Sill deflection at far end anchor bolt.
Appendix 4B
Test 21C
Load vs. Plywood Vertical Displacement

Plywood deflection at ram end.

Plywood deflection at far end.
Appendix 4B
Test 21C
Load vs. Sill Vertical Displacement Near Plywood

Sill deflection at far end.

Sill deflection at ram end.
Appendix 4B
Test 21C
Load vs. Sill Vertical Displacement Away From Plywood

Applied Load (lbs.) vs. Vertical Deflection (in.)
Sill deflection at far end.
Sill deflection at ram end.
Appendix 4B
Test 21C
Load vs. Wall Diagonal Elongation

Diagonal elongation bottom right to top left.

Diagonal elongation bottom left to top right.
## Appendix 5:
### Group 4 (w/ Holdowns) Test Results

$Q_0 = 14,000$lbs

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Wood Species</th>
<th>Nominal Sill Plate Size</th>
<th>Bolt Diameter</th>
<th>Nut/Washer</th>
<th>Dead Load (plf)</th>
<th>Ultimate Load (plf)</th>
<th>Ratio of $Q_0$</th>
<th># of Primary Cycles</th>
<th>Sill Failure</th>
<th>Plywood Nail Failure</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8, 20-in. from end of wall</td>
<td>Smooth rod w/ no nut or washer</td>
<td>100</td>
<td>1222</td>
<td>0.7</td>
<td>4</td>
<td>X</td>
<td>Simpson HTT22 Holdown, 1/2-inch plywood, Max load = 9775# (1222 plf)</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8, 8-in. from end of wall</td>
<td>Smooth rod w/ no nut or washer</td>
<td>100</td>
<td>1226</td>
<td>0.7</td>
<td>4</td>
<td>X</td>
<td>Simpson HTT22 Holdown, 1/2-inch plywood, Max load = 9808# (1226 plf)</td>
<td></td>
</tr>
<tr>
<td>22-4c</td>
<td>Hem Fir</td>
<td>2 x 6</td>
<td>5/8, 8-in. from end of wall</td>
<td>Smooth rod w/ no nut or washer</td>
<td>100</td>
<td>1400</td>
<td>0.8</td>
<td>5</td>
<td>X</td>
<td>Simpson HTT22 Holdown, 1/2-inch plywood, Max load = 11196# (1400 plf)</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Hem Fir</td>
<td>2 x 6</td>
<td>5/8, 8-in. from end of wall</td>
<td>Threaded rod w/ no nut or washer</td>
<td>100</td>
<td>1306</td>
<td>0.8</td>
<td>5</td>
<td>X</td>
<td>Simpson HTT22 Holdown, 1/2-inch plywood, Max load = 11196# (1400 plf). Double 2x end post split.</td>
<td></td>
</tr>
<tr>
<td>41c</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8, 20-in. from end of wall</td>
<td>Special 3 in. sq. by 1/2-inch plate w/ slot</td>
<td>100</td>
<td>Not reliable data. See Test 41b.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No data, embedment of retrofitted holdown rod insufficient. Holdown at end stud - PHD5 w/ double end studs</td>
</tr>
<tr>
<td>41b</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8, 20-in. from end of wall</td>
<td>Special 3-inch square by 1/2-inch plate w/ slot</td>
<td>100</td>
<td>927</td>
<td>0.5</td>
<td>1</td>
<td>See comments.</td>
<td>Double end studs not stitched together, lags for PHD5 split studs. Double 2x end post split.</td>
<td></td>
</tr>
</tbody>
</table>
## Appendix 5(continued):
### Group 4 (w/ Holdowns) Test Results

\[ Q_0 = 14,000 \text{lbs} \]

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Wood Species</th>
<th>Nominal Sill Plate Size</th>
<th>Bolt Diameter</th>
<th>Nut/Washer</th>
<th>Dead Load (plf)</th>
<th>Ultimate Load (plf)</th>
<th>Ratio of ( Q_0 )</th>
<th># of Primary Cycles</th>
<th>Sill Failure</th>
<th>Plywood Nail Failure</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>41b-4x4.1</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8, 20-in. from end of wall</td>
<td>Special 3 in. sq. by 1/2 in. pl. w/ slot</td>
<td>100</td>
<td>1758</td>
<td>1.0</td>
<td>1</td>
<td>See comments.</td>
<td>Runaway loading ram, one cycle to ultimate, failure at plywood joint at center, PHD5 w/ 4x4 end studs</td>
<td></td>
</tr>
<tr>
<td>41b-4x4.2</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8, 20-in. from end of wall</td>
<td>Special 3 in. sq. by 1/2 in. pl. w/ slot</td>
<td>100</td>
<td>1041</td>
<td>0.6</td>
<td>3</td>
<td>See comments.</td>
<td>Failure at plywood joint at center, PHD5 w/ 4x4 end studs, 1/2-inch plywood, Max load = 8330# (1041 plf)</td>
<td></td>
</tr>
<tr>
<td>41b-4x4.3</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8, 20-in. from end of wall</td>
<td>Special 3 in. sq. by 1/2 in. pl. w/ slot</td>
<td>100</td>
<td>1576</td>
<td>0.9</td>
<td>6</td>
<td>X</td>
<td>PHD5 w/ 4x4 end studs, 4x4 at plywood joint at center, 1/2-inch plywood, Max load = 8330# (1041 plf)</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8, 8-in. from end of wall</td>
<td>Special 3 in. sq. by 1/2 in. pl. w/ slot</td>
<td>100</td>
<td>1545</td>
<td>0.9</td>
<td>6</td>
<td>See comments.</td>
<td>No failures, wall softened, +/- 6-inches, PHD5 w/ 4x4 end studs, 4x4 at plywood joint at center, 1/2-inch plywood, Max load = 12362# (1545 plf)</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8, 20-in. from end of wall</td>
<td>Round</td>
<td>100</td>
<td>1395</td>
<td>0.8</td>
<td>5</td>
<td>X</td>
<td>PHD5 w/ 4x4 end studs, 4x4 at plywood joint at center, 1/2-inch plywood, Max load = 11158# (1395 plf)</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>Hem Fir</td>
<td>2 x 6</td>
<td>5/8, 20-in. from end of wall</td>
<td>2 in. sq. by 3/16 in. washer</td>
<td>100</td>
<td>1046</td>
<td>0.6</td>
<td>3</td>
<td>See comments.</td>
<td>End studs split at row of nails, PHD5 w/ double end studs nailed w/ two rows - 10d common at 3-inches, triple studs at plywood joint at center nailed w/ two rows - 10d common at 3-inches, 1/2-inch plywood, Max load = 8370# (1046 plf)</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>Hem Fir</td>
<td>2 x 6</td>
<td>5/8, 8-in. from end of wall</td>
<td>5-inch square by 1/2-inch plate</td>
<td>100</td>
<td>1215</td>
<td>0.7</td>
<td>4</td>
<td>X</td>
<td>PHD5 w/ 4x6 end studs, 4x6 at plywood joint at center, 1/2-inch plywood, Max load = 9718# (1215 plf)</td>
<td></td>
</tr>
</tbody>
</table>
### Appendix 5 (continued):
#### Group 4 (w/ Holdowns) Test Results

\[ Q_0 = 14,000 \text{ lbs} \]

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Wood Species</th>
<th>Nominal Sill Plate Size</th>
<th>Bolt Diameter</th>
<th>Nut/Washer</th>
<th>Dead Load (plf)</th>
<th>Ultimate Load (plf)</th>
<th>Ratio of ( Q_0 )</th>
<th># of Primary Cycles</th>
<th>Sill Failure</th>
<th>Plywood Nail Failure</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>46</td>
<td>Hem Fir</td>
<td>2 x 6</td>
<td>5/8, 20-in. from end of wall</td>
<td>Round</td>
<td>100</td>
<td>1244</td>
<td>0.7</td>
<td>4</td>
<td>X</td>
<td></td>
<td>PHD5 w/ 4x6 end studs, 4x6 at plywood joint at center, 1/2-inch plywood, Max load = 9954# (1244 plf)</td>
</tr>
<tr>
<td>50</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8, 20-in. from end of wall</td>
<td>Special 3 in. sq. by 1/2 in. pl. w/ slot</td>
<td>100</td>
<td>1222</td>
<td>0.7</td>
<td>4</td>
<td>See comments.</td>
<td></td>
<td>HTT22 failed, HTT22 w/ 4x4 end studs, 4x4 at plywood joint at center, 1/2-inch plywood, Max load = 9778# (1222 plf)</td>
</tr>
<tr>
<td>51</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8, 8-in. from end of wall</td>
<td>Ends: 3 in. sq. by 3/16 in. pl. washer. Int: Std round washer</td>
<td>100</td>
<td>1221</td>
<td>0.7</td>
<td>4</td>
<td>See comments.</td>
<td></td>
<td>End post split at lags for PHD5. 3x3 washer bent, PHD5 w/ 4x4 end post, 4x4 at plywood joint at center, 1/2-inch plywood, Max load = 9771# (1221 plf)</td>
</tr>
<tr>
<td>52</td>
<td>Hem Fir</td>
<td>2 x 4</td>
<td>5/8, 8-in. from end of wall</td>
<td>Ends: 3 in. sq. by 1/4 in. pl. washer. Int: Std round washer</td>
<td>100</td>
<td>871</td>
<td>0.5</td>
<td>2</td>
<td>See comments.</td>
<td></td>
<td>End post split at lags for PHD5. PHD5 w/ 4x4 end post, 4x4 at plywood joint at center, 1/2-inch plywood, Max load = 6969# (871 plf)</td>
</tr>
<tr>
<td>47</td>
<td>Doug Fir</td>
<td>Upper Hem Fir Lower</td>
<td>2 x 4 upper &amp; 2 x 6 lower</td>
<td>5/8, 8-in. from end of wall</td>
<td>Round</td>
<td>100</td>
<td>1391</td>
<td>0.8</td>
<td>5</td>
<td>See comments.</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>Doug Fir</td>
<td>Upper Hem Fir Lower</td>
<td>2 x 4 upper &amp; 2 x 6 lower</td>
<td>5/8, 8-in. from end of wall</td>
<td>Round</td>
<td>100</td>
<td>1189</td>
<td>0.7</td>
<td>4</td>
<td>See comments.</td>
<td></td>
</tr>
</tbody>
</table>
### Appendix 5(continued):

**Group 4 (w/ Holdowns) Test Results**

\[ Q_0 = 14,000 \text{ lbs} \]

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Wood Species</th>
<th>Nominal Sill Plate Size</th>
<th>Bolt Diameter</th>
<th>Nut/Washer</th>
<th>Dead Load (plf)</th>
<th>Ultimate Load (plf)</th>
<th>Ratio of ( Q_0 )</th>
<th># of Primary Cycles</th>
<th>Sill Failure</th>
<th>Plywood Nail Failure</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>49</td>
<td>Douglas Fir Upper Hem Fir Lower</td>
<td>3 x 4 upper &amp; 2 x 6 lower</td>
<td>5/8, 8-in. from end of wall</td>
<td>Round</td>
<td>100</td>
<td>1410</td>
<td>0.8</td>
<td>5</td>
<td>X</td>
<td>plywood nails pulled out or through plywood followed by blocks lifting, No damage to sill or blocks. PHD5 w/ 4x4 end studs, 4x4 at plywood joint at center, 3x upper block to sill w/ 40 - 20d galv. Box (2-1/2-inches o.c.), 1/2-inch plywood, Max load = 11121# (1410 plf)</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>Douglas Fir</td>
<td>3 x 4</td>
<td>5/8, 8-in. from end of wall</td>
<td>2-1/2 in. sq. by 1/4-inch washer</td>
<td>100</td>
<td>1162</td>
<td>0.7</td>
<td>4</td>
<td>See comments.</td>
<td>End post split at lags for PHD5. PHD5 w/ 4x4 end post, 4x4 at plywood joint at center, 1/2-inch plywood, Max load = 9296# (1162 plf)</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>Douglas Fir</td>
<td>3 x 6</td>
<td>5/8, 8-in. from end of wall</td>
<td>2-1/2 in. sq. by 1/4-inch washer</td>
<td>100</td>
<td>1256</td>
<td>0.7</td>
<td>4</td>
<td>See comments</td>
<td>End post split at knot above HTT22. HTT22 w/ 4x4 end post, 4x4 at plywood joint at center, 1/2-inch plywood, Max load = 9837# (1256 plf)</td>
<td></td>
</tr>
</tbody>
</table>

**General Notes:**

1. \( Q_0 = 14,000 \text{ lbs} \)
2. Standard cut washer = 1-1/2 +/- inch diameter, Oversized plate washer = 2-inch square by 3/16-inch thick, Full plate-width washer = 2-1/2-inch square by 1/4-inch
3. Slotted plate = Simpson LBPS 5/8
4. 3-inch square by 1/2-inch thick plate = Slotted 3-inch square by 1/2-inch thick plate
5. Sill Plates: Selected sill randomly with varying grain and log size.
6. Anchor bolts secured finger tight PLUS 1/4 turn
7. Sills face nailed to studs unless otherwise noted
8. Gun Nails for Plywood: Full heads, Not Overdriven
Appendix 5B
Test 19
Load vs. Time History

Applied Load (lbs.)

Time (hh:mm:ss)

1222 plf
70% of $Q_0$
$Q_0=14000$lbs.
Appendix 5B
Test 19C
Load vs. Deflection at Top of Wall

Applied Load (lbs.) vs. Horizontal Deflection (in.).

- 1222 plf
- 70% of $Q_0$
- $Q_0=14000$ lbs
Appendix 5B
Test 19
Load vs. Sill Vertical Displacement at Anchor Bolts

Sill deflection at ram end anchor bolt.
Sill deflection at first interior anchor bolt.
Sill deflection at second interior anchor bolt.
Sill deflection at far end anchor bolt.
Appendix 5B
Test 19
Load vs. Sill Horizontal Displacement at Anchor Bolts

- Sill deflection at first interior anchor bolt.
- Sill deflection at far end anchor bolt.
- Sill deflection at second interior anchor bolt.
- Sill deflection at ram end anchor bolt.
Appendix 5B
Test 19
Load vs. Plywood Vertical Displacement

Plywood deflection at ram end.
Plywood deflection at far end.
Appendix 5B
Test 19
Load vs. Sill Vertical Displacement Near Plywood

Sill deflection at far end.

Sill deflection at ram end.
Appendix 5B
Test 19
Load vs. Sill Vertical Displacement Away From Plywood

Sill deflection at far end.

Sill deflection at ram end.
Diagonal elongation bottom right to top left.

Diagonal elongation bottom left to top right.
Appendix 5C
Test 42C
Load vs. Time History

Applied Load (lbs.)

1545 plf
88% of Q₀
Q₀=14000 lbs.
### Appendix 5C

#### Test 42C

**Load vs. Deflection at Top of Wall**

<table>
<thead>
<tr>
<th>Applied Load (lbs.)</th>
<th>Horizontal Deflection (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>88% of $Q_0$</td>
<td>$Q_0 = 14000$ lbs.</td>
</tr>
</tbody>
</table>

**1545 plf**

88% of $Q_0$
Appendix 5C
Test 42C
Load vs. Sill Vertical Displacement at Anchor Bolts

Sill deflection at first interior anchor bolt.
Sill deflection at second interior anchor bolt.
Sill deflection at far end anchor bolt.
Sill deflection at ram end anchor bolt.
Appendix 5C
Test 42C
Load vs. Sill Horizontal Displacement at Anchor Bolts

- Sill deflection at ram end anchor bolt.
- Sill deflection at first interior anchor bolt.
- Sill deflection at second interior anchor bolt.
- Sill deflection at far end anchor bolt.

Applled Load (lbs.) vs. Horizontal Deflection (in.)
Appendix 5C
Test 42C
Load vs. Plywood Vertical Displacement

Plywood deflection at ram end.
Plywood deflection at far end.
Appendix 5C
Test 42C
Load vs. Sill Vertical Displacement Near Plywood

Vertical Deflection (in.)
-0.40 -0.30 -0.20 -0.10 0.00 0.10 0.20 0.30 0.40 0.50
Applied Load (lbs.)
-14000 -12000 -10000 -8000 -6000 -4000 -2000 0 2000 4000 6000 8000 10000 12000 14000
Appendix 5C
Test 42C
Load vs. Sill Vertical Displacement Away From Plywood

Sill deflection at ram end.
Sill deflection at far end.
Appendix 5C
Test 42C
Load vs. Wall Diagonal Elongation

Diagonal elongation bottom left to top right.

Diagonal elongation bottom right to top left.
Appendix 5D
Test 51
Load vs. Time History

Applied Load (lbs.)

Time (hh:mm:ss)

1221 plf
70% of $Q_0$
$Q_0=14000$ lbs
Appendix 5D
Test 51C
Load vs. Deflection at Top of Wall

1221 plf
70% of $Q_0$
$Q_0=14000$ lbs.
Appendix 5D
Test 51
Load vs. Sill Vertical Displacement at Anchor Bolts

- Sill deflection at far end.
- Sill deflection at second interior anchor bolt.
- Sill deflection at first interior anchor bolt.
Appendix 5D
Test 51
Load vs. Sill Horizontal Displacement at Anchor Bolts

Sill deflection at first interior anchor bolt.

Sill deflection at ram end anchor bolt.

Sill deflection at second interior anchor bolt.

Sill deflection at far end anchor bolt.
Appendix 5D
Test 51
Load vs. Plywood Vertical Displacement

Applied Load (lbs.)

Plywood deflection at far end.

Plywood deflection at ram end.
Appendix 5D
Test 51
Load vs. Sill Vertical Displacement Near Plywood

Sill deflection at far end.

Sill deflection at ram end.
Appendix 5D
Test 51
Load vs. Sill Vertical Displacement Away From Plywood

![Graph showing load vs. sill vertical displacement away from plywood.](image-url)
Appendix 5D
Test 51
Load vs. Wall Diagonal Elongation

Diagonal elongation bottom right to top left.

Diagonal elongation bottom left to top right.