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TECHNICAL REPORT

Results of Cyclic (Reversed) Load Testing For Shear Resistance Of Wood Framed Plywood Shear Walls with USP Lumber Connector Hold-Downs

SEAOSC Testing Protocol 9/97

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EXECUTIVE SUMMARY

The following report summarizes cyclic (reversed) load testing performed on plywood sheathed shear walls on wood framing, using code required bolted or nailed hold-down devices installed at the inside of the end post. The testing was performed in conformance with the Structural Engineers Association of Southern California (SEAOSC) "Standard Method of Cyclic (Reversed) Load Test for Shear Resistance of Framed Walls for Buildings", January 1997 (Reference 1).
The hold-down devices used in the component panel systems were manufactured by USP Lumber Connectors of Montgomery, Minnesota, the test sponsor. A non-proprietary fabricated steel channel hold-down using shear plated bolts at the end-post connection was also tested, to develop comparative data. This hold-down called the SHD7 was provided and developed by Ben Schmid, S.E.

The testing was performed for the following purposes:

- To provide the sponsor's technical staff with insight as to the overall performance of wood framed shear walls in a cyclical test environment
- To provide comparative data using the sponsor's hold-down devices, for other shear wall and hold-down device testing being conducted (COLA and APA)
- To provide performance data concerning whether the common engineering design practice of neglecting combined bending action on shear wall end-posts induced by use of eccentric hold-down devices is unconservative
- To test the limiting performance of the hold-down devices. Plywood sheathing capacity was selected to develop as a minimum 100% of the allowable hold-down capacity, with up to 50% overstress in some hold-downs.
- To provide research data for future new product development

Two samples each from thirteen different USP hold-downs were tested as a part of thirteen component systems. Additionally, one SHD7 was tested as a control. In the first phase of testing, thirteen full sized plywood sheathed wall panels, seven with 8-foot height by 8-foot length, and six with 8-foot height and 4-foot length were tested on July 20 and 21, 1999. In the second phase of testing, thirteen additional full sized plywood sheathed wall panels having the same configurations as the first round of testing, and one utilizing the SHD 7 were tested on September 1 through 3, 1999. All testing was performed at the University of California, Irvine, Structures Lab.

The plywood panel configurations represent extreme conditions with respect to the hold-down and end-post tension and sill crushing. Based on the extreme loading conditions, the panel specimens were not fully representative of normal code required plywood shear wall design and construction with regards to end-post sizing for sill plate bearing, and hold-down capacity. Plywood sheathing and nailing used in the test panels were selected from the UBC using the allowable shear capacity tables to develop as a minimum, the working-stress uplift capacity of each hold-down. For this purpose, hold-down allowable stresses were based on the manufacturer's ICBO approved allowable stress design uplift capacity.

In order to assess the possible effects of eccentric bending in the end-post, end posts were sized primarily by consideration of gross tension. Combined bending and tension due to eccentricity between the hold-down anchor-bolt and the end-posts were not considered for end-post sizing purposes. Based on the end-post sizes used, overstresses of up to 60% in the UBC allowable perpendicular-to-grain bearing capacity (for deflection-critical bearings) were permitted on the sill plates, so that the testing for possible end-post failure due to potential flexural stresses due to eccentricity at the end-posts could be implemented.

TEST PANEL DESCRIPTION

General

Fourteen shear wall test panel groups were tested, as outlined in Table 1. Two samples per group were tested for Groups 1 through 13, and one for Group 14, for a total of 27 tested panels. Each test group utilized a different hold-down device, with one of two panel configurations. The first panel configuration has overall dimensions of 8-feet wide by 8-feet high (1:1 aspect ratio), and was sheathed on one side only, as shown in Figure 1. The second panel configuration has overall dimensions of 4-feet wide by 8-feet high (2:1 aspect ratio), and was sheathed on both sides, as shown in Figure 2. All framing and nailing was in conformance with Table 23-II-I-1of the 1997 UBC for the plywood sheathing used.

Group 14 utilized fabricated SHD7 hold-downs as developed by Ben Schmid S.E. and utilized shear plates. This test was used as a control comparison for hold-down stiffness effects on shear wall performance and strength.

Materials

The wood framing was nailed in accordance with UBC 1997 Table 23-II-B-1 using common nails. Wood framing was standard visually graded surfaced Douglas Fir-Larch dimension lumber (S.G. = 0.50), dry (moisture content less than 19%). The measured moisture content (MC) for the wood used in these tests was between 12% and 19%. Materials used in the fabrication and construction of the component systems consisted of the following:

Plywood: APA rated STR I plywood sheathing in standard 4-foot by 8-foot sheets, 3/8-inch (3-ply) and 15/32-inch thick (4-ply) as specified.

Nails: “Sterling” nails, manufactured by Northwestern Wire & Steel, bright finish.

F_{yb} = 130 ksi for 8d and 10d common nails assumed (Ref. NDS)
F_{yb} = 115 ksi for 16d common nails assumed (Ref. NDS)

Plywood nailing: 10d and 8d common nails, with edge and field spacing as specified. The plywood edge distance for 3-inch and larger nail spacing was 3/4-inch. Plywood edge distance for staggered 2-inch nail spacing was as follows:

- 3/4-inch and 1-3/4-inch at the sill and end-posts
- 5/8-inch and 3/4-inch at the 3x4 center post
- 3/4-inch and 2 1/4-inch (respectively) into the upper and lower 2x top plates

Nails were driven flush with the sheathing in accordance with UBC 2314.1.

Sill bolts: 5/8-inch diameter ASTM A307 machine bolts with 2-2½-inch square by ¼-inch ASTM A36 plate washers, and hex nuts. Holes for the sill bolts were drilled using 11/16-inch diameter bits. Refer to Figures 1 and 2 and Table 1 for sill bolt number and spacing.

Sill plates: 3x4 DF-L, No. 2 & Btr., untreated. Sill plates for 8-foot long wall panels were continuous with no notches.

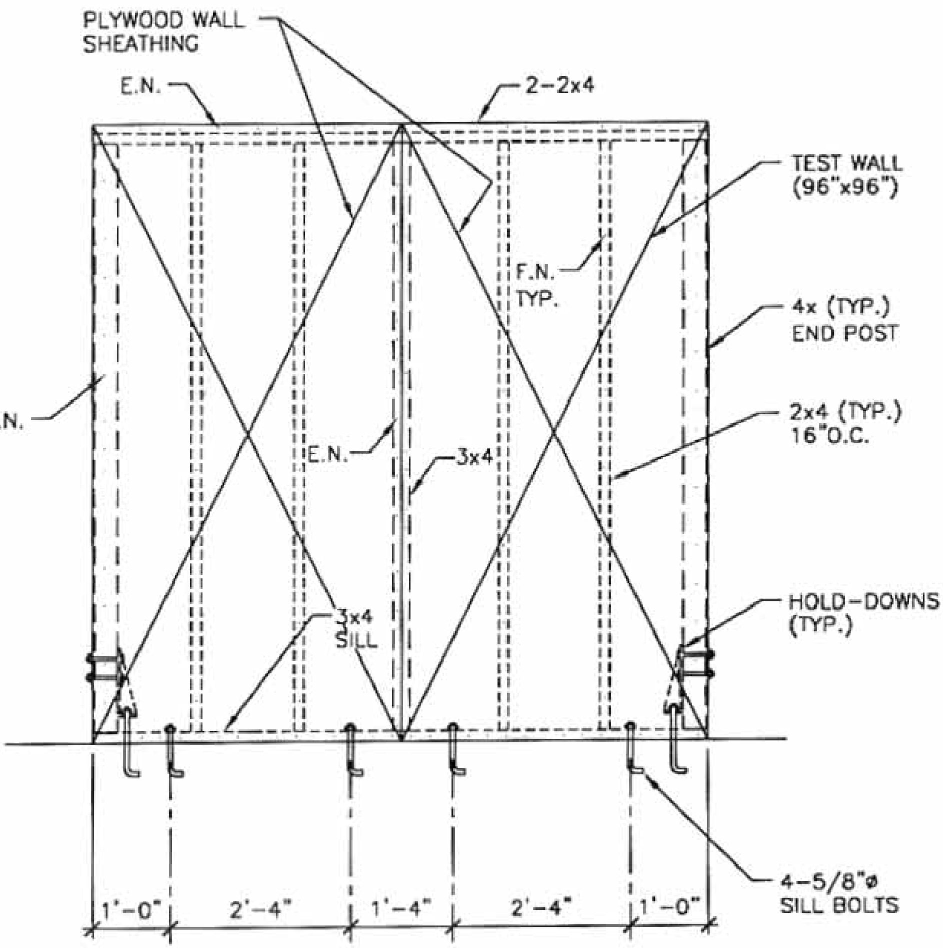

Figure 1 – 8'-0" x 8'-0" Plywood Test Panel with Plywood Sheathing on One Side

Top plates: 2-2x4 DF-L, No. 2 & Btr., untreated, face nailed with 16d common nails @ 16-inches on center. Top plates for 8-foot long wall panels were continuous with no notches.

End posts: 4x4 DF-L Std. & Btr. or 4x6 DF-L No. 2., installed between the sill and double top plates (end nailed with 2-16d from plate into the ends of the post).

Wall studs: 2x4 DF-L, No. 2 & Btr. (end nailed to top and sill plates). Wall studs at adjoining plywood panel edges were 3x4 DF-L, No. 2 & Btr.

USP Hold-Down brackets: Manufactured by USP Lumber Connectors, as specified for each test, with end-post attachment hardware as specified in Table 1. Refer to Appendix P for geometry and construction. Hold-down materials and agency approval number are as follows:

- TD/TDX ASTM A570 Grade 33 (F_y = 33,000 psi, F_u = 52,000 psi)
  ICBO ER-5125, LARR 25332, 23888
- HTT ASTM A653 SQ Grade 33 (F_y = 33,000 psi, F_u = 45,000 psi)
  ICBO ER-537, LARR 25307
- ADS5 ASTM A653 SQ Grade 33
  ICBO NER-505, LARR 25303
- MTS 27B ASTM A653 SQ Grade 40
  ICBO ER-5531, LARR 25307

"Schmid" SHD 7 Hold-Down bracket: Shop fabricated and welded ASTM A36, MC 3x7.1 body with ½-inch bolt setting plate. Used with two ¾-inch diameter bolts with 2 5/8-inch diameter shear plates (in conformance with the NDS, Reference 3), installed at the end-post. Refer to APA Report 158 (Reference 4) and Appendix P for hold-down dimensions and properties.

Anchor bolts: ASTM A193 B7 (Fy = 105,000 psi) high strength threaded rod material. The anchor bolt diameters used in the tests were equal to or smaller than the Manufacturer's recommended sizes for anchor bolts. The use of high strength anchor bolt material and (sometimes) smaller anchor bolt diameter was utilized as a testing convenience, so that the anchor bolts did not need to be replaced after every test.

Design of Test Panel Plywood Sheathing and Hold-Down Devices

These tests represent extreme loading conditions, and do not represent design and construction in full compliance with the UBC code provisions and criteria. These extreme loading conditions were intentionally generated to accentuate the behavior of the hold-down hardware, hold-down anchor bolt, and alleged combined bending and axial tension effects on the shear wall boundary post. Because added gravity loads were not included in the testing, these panels are more representative of single-story non-bearing shear walls.

Structural panels were designed for each group to develop the expected uplift capacity of the hold-down used for each test. The magnitude of the expected force levels was based on previous testing (References 4 and 5) and by estimates of panel shear strength at the strength limit state. As such, the hold-downs in these tests are sometimes heavily overstressed (demand-to-capacity ratio, or D/C greater than 1.1) based on current design methodologies. A summary of the

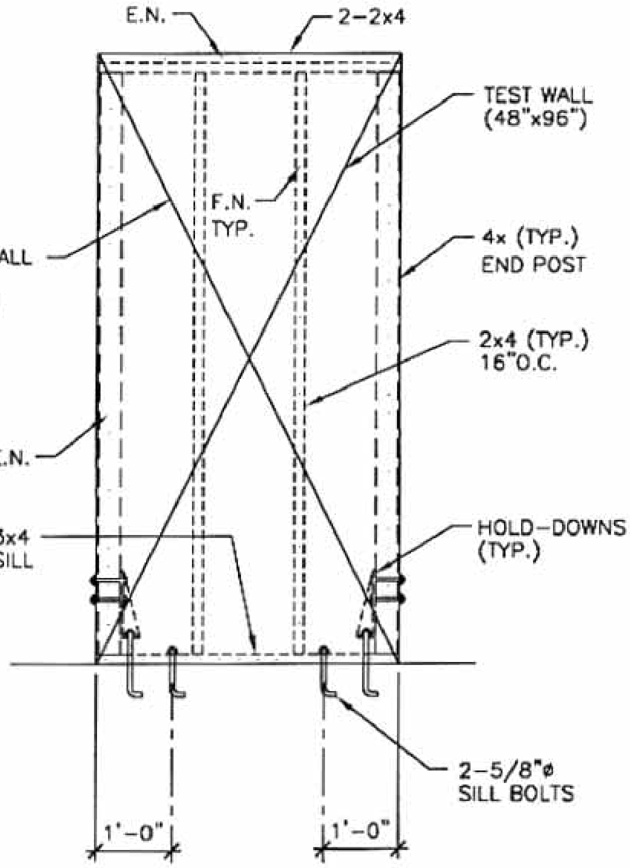

Figure 2 – 8'-0" x 4'-0" Plywood Test Panel with Plywood Sheathing on Two Sides

components used for each testing group, and the estimated lateral capacity and source are presented in Table 2.

Hold-down and plywood nailing assignments were calculated in most cases using the published allowable uplift value of each hold-down and the test panel geometry, and then determining the required shear necessary to develop the allowable uplift in the hold-down. Dead weight of the test panel itself was neglected. Most hold-downs were sized using the 1.33 load duration factor allowed for wood connection in the UBC (Reference 2).

> *NOTE: Table 2.3.2 of the 1997 UBC, Chapter 23, Division III, limits the allowable stress increase for short-term duration wind and seismic loads for wood members and hold-down devices to 1.33.*

Plywood thickness, grade, and edge nailing was then selected to develop as a minimum the published allowable uplift of the hold-down using the values in the 1997 UBC, Table 23—II-I-1 allowable plywood shear wall capacity. The wall framing for sill plates, and studs at double edge panel nailing, were also selected to be in general conformance with the 1997 UBC.

In order to assess the possible effects of eccentric bending in the end-post, end posts were sized primarily by consideration of gross tension. Combined bending and tension due to eccentricity between the hold-down anchor-bolt and the end-posts were not considered for end-post sizing purposes. A comparison of the end-posts as tested, and the normal code required end-post design is shown in Table 3. The majority of the end-posts used in the tests are undersized compared to end-posts designed using the required design criteria in the UBC and NDS. Based on the end-post sizes used, overstresses of up to 60% in the UBC allowable perpendicular-to-grain bearing capacity (for deflection-critical bearings) were permitted on the sill plates, so that the testing for possible end-post failure due to potential flexural stresses due to eccentricity at the end-posts could be implemented. End posts were assumed to be 4x4 minimum, but were increased to 4x6 where consideration of the gross section tension stress and sill bearing stress indicated the need for a larger end post. For end-post sizing purposes, the load duration factor for tension was limited to 1.33, and the load duration factor for bearing was limited to 1.0, following the requirements of the 1997 UBC.

Test Panel Construction

Typical wall panel configurations used in the testing are shown in Figures 1 and 2. Framing was constructed no more than 4 days before actual testing. The first side of plywood panels was installed no more than 48-hours prior to testing. The second side of plywood panels (for two-sided panels) was nailed just prior to the time of testing, under the observation of the Structural Engineer.

All wood framing and nailing was in conformance with Section 2315, and Table 23-II-I-1, of the 1997 UBC, and as outlined in the Test Panel Materials Section, above. All nailing was performed by hand and/or with a mechanical palm nailer. Hold-down devices were installed at the centerlines of wood end-posts, facing inward, with the attachment hardware and spacing as specified in Table 1.

For double sheathed shear walls, ½-inch plywood doubler plates, 7-inches by 9-inches, were added at the lower panel corners on one side to mitigate the effect of displacement transducer access holes at that side (see Photograph 1). The doubler plates were stapled to the plywood panels only at the corner of the wall on one side, then two overlapping 3-inch diameter holes were drilled toward the middle of each plate. The staples used did not penetrate into the framing. In addition, at the top of each hold-down, a 2-inch diameter hole was drilled to allow for observation and the passage of displacement transducer wiring at these locations. The validity of the test results was considered to be essentially unaffected by the addition of the doubler plates and openings in the plywood.

No gypsum board, plaster, or any other finish was added to the test panels.

TESTING APPARATUS

Figure 3 and Photographs 2-5 show the configuration of the testing rack and recording apparatus used. Wall panels were attached at the sill plate to a rigid steel testing-rail, bolted to the concrete floor of the test lab. The testing-rail allowed for adjustment of the sill and anchor bolt spacing and bolt diameters. The top of the test panel was laterally braced against out-of-plane movement with steel frames, but was allowed to rotate and displace in the plane of the wall (cantilever wall condition). A steel channel was lag bolted to the top plates (using pre-drilled holes), which in turn was attached to a loading ram parallel to the channel. Based on the relative stiffness of the steel channel to the top plates, the lateral (racking-shear) loads were applied uniformly at the top of the wall. The loading ram was operated cyclically by a computer under displacement control at a frequency and magnitude of displacement in conformance with the testing protocol (Ref. 1). No superimposed vertical load on the panel other than the self-weight and the weight of the loading channel was present during the test. The weight of these elements was considered to be negligible.

Under cyclical displacement control, the net force at the top of the wall was recorded using a load transducer installed in-line with the hydraulic loading ram. In addition, six linear variable displacement transducers (LVDTs) for recording relative displacement vs. time and net force were wired for input into a computer workstation. An adjustable wire cable was attached at the center of the uppermost top plate with an eye screw, then put in-line with the LVDT at that station, and rigged to a rigid steel beam bolted to the testing-rail. All other LVDTs were set in an aluminum attachment bracket, with their plunger loaded against an aluminum backing-bracket. These LVDT brackets were installed using hot glue. The LVDTs were adjusted to have an approximate gage length of 5-inches.

During the cyclical testing, relative displacement between the following components was electronically measured and recorded, as a function of time and the racking shear force at the top of the panel:

- Horizontal displacement at the top plate (Photograph 2)
- Horizontal displacement at the sill plate (Photograph 5)
- Vertical displacement at each end post, relative to the rigid base (Photograph 4)
- Relative vertical displacement between each hold-downs and the end posts (Photographs 4, 5)

TESTING

Individual panels were tested in accordance with the SEAOSC testing protocol (Ref. 1). In accordance with the SEAOSC testing protocol, Section 7.4, the basis of the displacement magnitude for the tests was based on the First Major Event (FME), or Yield Limit State (YLS). This displacement for each wall was determined using estimates of the lateral deflections at the top of the walls based on the "City of LA Light Framed Shear Wall Research Project" (Reference 5). A summary of the estimated wall capacities for each group at the Strength Limit State (SLS) is shown in Table 5.

The moisture content was spot-checked on a random basis. Moisture content readings taken were between 12% and 19% in all cases. Based on the moisture content readings and the fact that the lumber was kiln dried, the moisture content was assumed to be less than 19%. Prior to each test, the following was performed:

- The panel assembly was reviewed by the Structural Engineer for general conformance with the specified sample construction parameters, including final panel assembly and attachment to the loading rig
- Correct placement of the LVDT deflection gages was confirmed
- The circuitry of each LVDT channel and the loading ram was verified and confirmed to be working properly
- The ambient temperature of the lab was recorded
- The date and approximate time of the test was recorded
- The sample group number was marked at various locations on the sample

During and following each test, the following was performed:

- A California Licensed Structural Engineer was present to observe the test
- LVDT and load data was fed into the computer
- Photographs were taken
- Some tests were selectively videotaped
- Behavioral observations and failure modes on the panel and panel components were noted
- Plywood on double-sided samples was removed in the vicinity of one hold-down for observation of the hold-down and adjacent framing members.

No loading data for the anchor bolts was recorded for these tests.

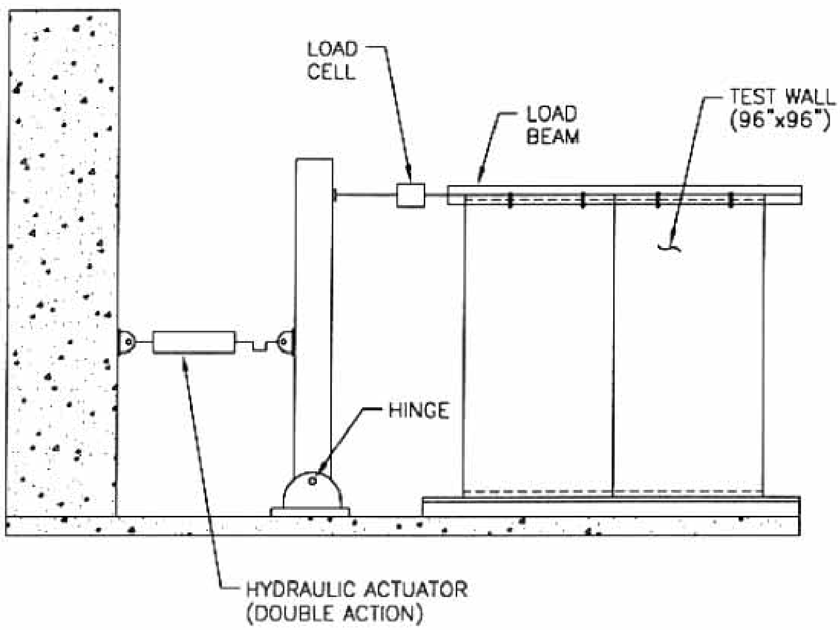

Figure 3 – Test Setup for Cyclic Load Plywood Shear Wall Tests

TESTING RESULTS

Load-Deformation Plots

Cyclical load-deformation data plots for each LVDT on a sample-by-sample basis is included in Appendices A through N, corresponding to the hold-down devices used as follows:

Appendix A	Group 1 – TD 2
Appendix B	Group 2 – TD 5
Appendix C	Group 3 – TD 9
Appendix D	Group 4 – TD 12
Appendix E	Group 5 – HTT 16
Appendix F	Group 6 – HTT 22
Appendix G	Group 7 – HTT 30
Appendix H	Group 8 – HTT 50
Appendix I	Group 9 – MTS 27B
Appendix J	Group 10 – ADS 5
Appendix K	Group 11 – TDX 6
Appendix L	Group 12 – TDX 10
Appendix M	Group 13 – ADS 14
Appendix N	Group 14 – SHD 7

The Figures provided in each Appendix (x) are as follows:

Figure x-1	Group Envelope Curve Plot
Figure x-2	Group Bilinear Representation Plots
Figure x-3	Group Average Bilinear Representation Plot
Figure x-4	Test A Racking Force -Displacement Plot
Figure x-5	Test B Racking Force -Displacement Plot
Figure x-6	Test A Sill Slip-Racking Force Plot
Figure x-7	Test B Sill Slip-Racking Force Plot
Figure x-8	Test A Left Post Uplift-Racking Force Plot
Figure x-9	Test B Left Post Uplift-Racking Force Plot
Figure x-10	Test A Right Post Uplift-Racking Force Plot
Figure x-11	Test B Right Post Uplift-Racking Force Plot
Figure x-12	Test A Left HD Post Slip-Racking Force Plot
Figure x-13	Test B Left HD Post Slip -Racking Force Plot
Figure x-14	Test A Right HD Post Slip -Racking Force Plot
Figure x-15	Test B Right HD Post Slip -Racking Force Plot

OBSERVATIONS

General Test Panel Behavior

The observed plywood behavior and nail holding patterns suggest that the framing essentially racks laterally like a pin-ended frame, with the plywood acting like a pair of diagonal struts resisting the lateral racking forces as well as resisting part of the vertical force component. The distortions of the plywood and end-post relative to each other and to the sill are shown in Photograph 8. As can be seen from the photograph, as the plywood racks, the nails distort and pull out, which allows the plywood to pull away from the framing. The photograph also shows damage to the plywood edge from delamination as a result of nail edge bearing.

A summary of the observations made during and after the testing is shown in Table 4. Most of the 1:1 aspect ratio (single-sided) wall samples reached the yielding limit state at a drift ratio corresponding to 0.5%, and the strength limit state at a drift ratio corresponding to 1.5%. Walls with a 2:1 aspect ratio (double- sided, samples 4, 8, 13, and 14) exhibited the yielding limit state at a drift ratio corresponding to about 1.0%, and the strength limit state at a drift ratio corresponding to 2.0% or greater. A difference between the wall panel stiffness for the 2:1 and 1:1 aspect ratio walls is expected to some degree, based on engineering knowledge. However, based on the magnitude of this difference, the drifts of the high aspect walls in these tests are greater than would be expected based on the relative stiffness based on aspect ratio. As discussed below and in the recommendations, the main source of additional drift can be attributed to sill crushing from undersized end-posts, and in some cases hold-down yielding.

The average yield capacity and average ultimate (strength limit state) panel capacity for each sample was compared the 1997 UBC (Reference 2) allowable shear capacity. All test samples developed the 1997 UBC allowable shear capacity of the plywood before the onset of the yield limit state, with the exception of Group 12, as shown in Table 2 summary. Single sided walls, with a 1:1 aspect ratio, exhibited an apparent factor of safety of approximately 1.8 to 2.2 at the strength limit state. Double-sided walls, with a 2:1 aspect ratio, exhibited an apparent factor of safety of approximately 1.5 to 1.8 at the strength limit state.

The main source of non-linear behavior was plywood nail yielding. The predominant failure mechanism for all but one of the test panels was nail yielding and metal fatigue of the nail at the corners of the panel, and peeling away of the plywood from the framing. The strength limit state was controlled by failure of the shear wall nailing for all of the samples, except for the Group 3A panel which failed at the end post. Some fracturing of the plywood panel edges in the vicinity of nails was observed. Minor delamination of the plys at the extreme lower corners of the panels was observed in a few specimens (Photograph 8).

After removal of the plywood, the nails in every sample were observed to have deformed in a similar manner (Photograph 6). Figure 4 is a schematic of the plywood nail holding patterns, as observed in the framing members after plywood removal. As can be seen from the character of the nail yielding in the vicinity of the hold-downs, the bending deformation of the end-post due to hold-down eccentricity is partially resisted by the nails. As can be seen from Figure 4, the stress trajectory and magnitude of yielding for the nails varies by location, and is suggestive of strut action at the corners, and shear action at the panel boundary. Nails at the extreme corners of the panels were inclined at an angle approximately 45 degrees. Nails near the middle third of the vertical and horizontal panel edges deformed nearly parallel to the grain of the wood framing.

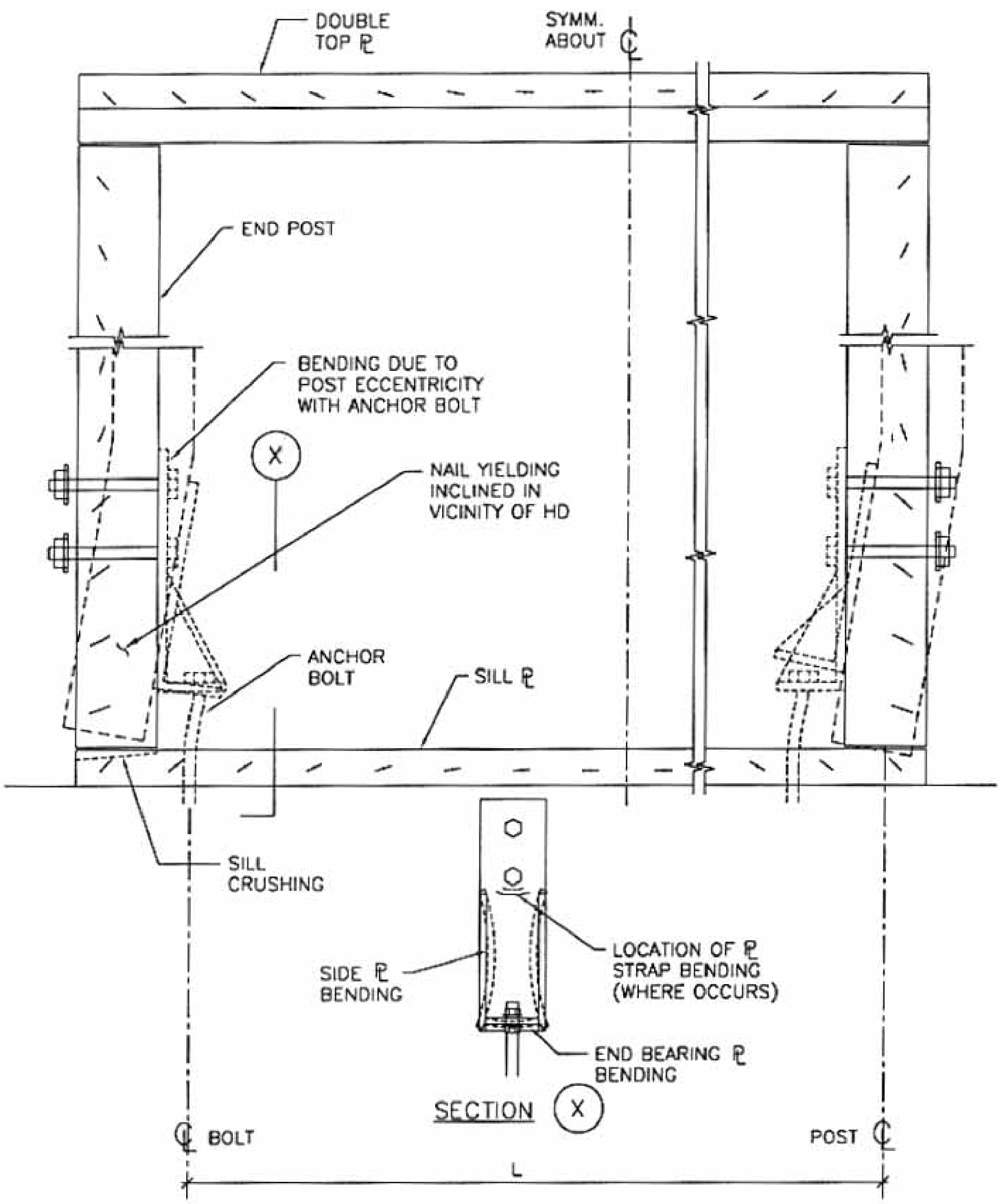

Figure 4 – Schematic of Typical Nail Holding Patterns Observed in Panel Framing

In general, the nail yielding was more severe at the lower corners than at the upper corners. At the maximum test panel drift of approximately 3.5%, the nails at the lower corners were bent so extremely by the laterally deflecting plywood panels that they either started to pull-out (Photograph 7), or were fractured at an approximate depth of 1/2-inch of embedment into the framing. A few occurrences of nail heads popping off were noted in this same area. This behavior was primarily limited to deflection well in excess of the strength limit state.

The sources of the higher levels of nail displacement and fatigue at the lower panel corners are the higher overturning forces at those locations, and to a lesser degree the additional relative displacement between the sill and the end-post. The major sources of the displacement between the sill and the end-post are yielding in the body of the hold-down, hold-down slip at the end-post, sill crushing, and end post bending in the vicinity of the hold-down.

Hold-Down Behavior

The general trend of the observed wall behavior was that a stiffer hold-down makes for a stiffer wall, since the deformation at the hold-down translates into drift at the top of the wall. However, the contribution of the relative stiffness of the hold-down on overall wall shear strength is not considered to be overly significant, though there is some correlation – as limiting the uplift deflection at the hold-down will reduce nail fatigue at the panel corners. One possible reason for the observed behavior in this regard is the observed equivalent-strut behavior of the wall panels – the shear wall nailing itself was observed to resist some of the vertical overturning forces at the panel corners.

No failure of any hold-down or hold-down connection was observed in any test. Referencing the last two columns of Table 2, the USP hold-downs exhibited an average overstress factor of 2.37 at the SLS and 1.65 at the YLS. Slip at the end-post to hold-down connection was less than 1/8-inch, and was generally twice as much in the bolted connections, than that in the nailed connections. Yielding in the body of the hold-downs was observed as follows:

- Significant yielding was observed on HTT Series at the wrapped end seats. Total deflection in the body of these connections was approximately 3/8-inches (Photograph 9)
- Significant yielding was observed on the MTS 27B hold-downs out-of-the-plane of the strap. The total deflection in the body of these connections was approximately 7/16-inches at the SLS
- Minor yielding was observed at the relatively thin anchor bolt seat plates on the TD 5 and ADS 14
- Slight dishing of the end plates was observed in the TDX 10 hold-downs

The most significant deflection mechanisms at the hold-down devices consisted of the following:

- Elastic any inelastic deformation in the body of the connection at the anchor bolt seats, and at the side stiffener plates, generally consisting of out-of-plane “plate” bending
- For strap connections: out-of-plane plate yielding in connection strap due to hold-down eccentricity at locations where the side stiffener plates end
- Bolt slip at the holes
- Geometric deflection of the hold-down at the end-post through end-post bending, due to eccentricity of the hold-down

Tables 6 and 6A summarize the relative sources of end-post and hold-down deflections based on the average for each group. Table 6A shows the vertical hold-down deflection as a ratio of the deflection at the top of the panel, and the relative hold-down stiffness as determined from the cyclic testing here and from monotonic testing previously performed by the manufacturer. Other sources of wall deflection such as plywood nail yielding and sill crushing, are not reflected in Table 6A. The effect of sill crushing on wall stiffness is discussed below.

End Post Behavior

End-posts were sized based on the following assumptions:

- End-posts were sized based primarily on uniform tensile stress, and neglected eccentric bending at the hold-down
- The gross area of the end-post was used in lieu of the net tension area
- Combined bending and tension due to eccentricity between the hold-downs and the end-posts was not considered
- End-posts were not sized considering reduced bearing stress perpendicular-to-grain on the sill plate

A significant concern regarding end-post selection occurred with bearing perpendicular-to-the-grain of the sill plate on the higher aspect walls, and is discussed in the relevant section below. While the above design criteria may have caused an apparent under-sizing of some end-posts, only one sample exhibited end-post failure (Sample 3A), and one end-post exhibited partial fracturing (Sample 12A). Splitting along the line of bolts was observed in the Group 14A – SHD 7 sample. The Group 3A and 12A end-post failures were at edge knots in the vicinity of the hold-down. The end-post failure in the Group 3A sample is shown in Photograph 10. The 4x6 end-post in 12A developed a crack during testing, but the post did not completely fracture. The damage to these end-posts can be attributed to local concentration of stresses at rather large edge knotholes. These knotholes were located at the inside face of the end post, approximately 2-inches from the top hold-down bolt.

One of the end-posts for the Group 14 (SHD 7) test panel split along the line of the bolted shear plates, as shown in Photograph 11.

The results of the testing with regards to end-post adequacy suggest that the practice of neglecting hold-down eccentricity in the design of the end post is reasonable for 4x4 and 4x6 end posts used in plywood sheathed shear walls. This conclusion is supported by reviewing the design ratios in Table 3, both considering combined bending and tension, and axial tension only. As can be seen from the table, the Demand-to-Capacity ratio (D/C) neglecting bending suggests general adequacy for most of the samples. However, when the D/C for the end-posts including eccentric bending are calculated, a trend of apparent gross inadequacy results. A finding of gross inadequacy of the end-posts is not supported by the bulk of the testing results.

The most probable reason for the observed adequacy of the end-posts is the bending restraint provided by the plywood nailing. Based on the observed direction of yielding shown in Figure 4 and Photograph 6, the plywood nailing in the vicinity of the hold-down resists a significant portion of the eccentric bending at the hold-down. The plywood nails near the hold-down are inclined much more horizontally, indicating that the nails at these locations resist bending of the end-post. Based on these observed nail yielding patterns in the framing, and the noted performance of the end-posts, the plywood nailing transfers some of the eccentric bending stresses into the sheathing, where it is taken out through gross rotation of the panel.

Sill Plate Behavior

Significant sill crushing especially at the strength limit state was observed at the ends of the 3x4 sills, especially on the higher aspect ratio walls. Photograph 11 shows the distortion of the sill plate in crushing due to end-post bearing. Sill crushing was expected based on the design overturning forces on the hold-downs, where the compressive stress perpendicular-to-grain exceeded 625 psi. Based on the 1997 UBC (NDS Section 4.2.6) requirements for sill bearing perpendicular-to-grain, excessive deflections were expected at the sill bearing where the compressive stress perpendicular-to-grain exceeded 0.73 x 625 = 456 psi. Several of the end-posts exceeded the code design allowable bearing stress of 456 psi, as shown in Table 3, and helps explain why excessive sill crushing damage was common during the testing even for some 1:1 aspect ratio walls.

The downward displacement at the extreme edge of the sill was observed to be on the order of 5/8-inch for the 2:1 aspect double sheathed walls. At the interior edge of the end-post measured deflections were on the order of 1/10-inch. Based on these findings, the perpendicular-to-grain bearing deflections at the sill plate are not uniform, and caused an average end-post deflection on the order of 5/16-inch. Thus, the 3x4 sill crushing on these samples corresponds to a drift at the top of the wall of approximately 0.6% (0.006) for the strength limit state. Sill crushing of this magnitude corresponds to approximately 20% to 30% of the total wall drift. Adding roof and floor gravity loads on actual shear walls could be expected to increase the level of sill crushing and further increase wall drift.

In some samples, the sill plates were observed to uplift at the wall panel ends between the sill bolt and the sill free end. The source of sill uplift was the elongation of the hold-down anchor bolt and deformation at the hold-down, which allowed the wall panel as a whole to rock at the base and uplift at the end. This deflection is accounted for in the end-post deflection measurements recorded during testing.

The lateral displacement at the bottom plate relative to the rigid base had a relatively small contribution to the overall panel deflection in all cases, and was typically less than 0.005-inches. However, based on the normal code required design criteria for wood in the UBC, all of the sill bolt connections on the 2:1 aspect ratio walls were overstressed by a factor up to D/C = 1.9 for the panels with 2/12 plywood nail spacing. The UBC allowable capacity for the sill-bolts is shown in Table 1. The fact that the sill-bolt yielding mechanism did not contribute to significant horizontal deflection at the sill for these walls is probably due to the contribution of the following mechanisms:

- Hold-down anchor-bolt contribution to the sill shear capacity
- Sliding friction developed against the steel testing rail at the compression side end-post, a function of the anchor bolt uplift load on the tension post and the static sliding friction coefficient
- Sill-bolt connection overstrength.

Anchor Bolt Behavior from Analysis

The ASTM A193 high strength bolt material was used as a testing convenience to prevent yielding in the body of the bolt, so the bolts did not need to be replaced for every test. As a result, anchor bolts were not a significant source of hold-down deflection. The estimated elastic anchor bolt deflections accounted for less than 2% of the overall SLS racking displacement for every group.

Based on a review of the estimated uplift demand on the anchor bolts during the testing, none of the high-strength anchor bolts reached the yield point during the testing (refer to Table 6). However, for some test panels, the more typically specified ASTM A307 anchor bolts (F_y = 36 ksi) of a diameter specified on the manufacturer's data sheets for use with the hold-down would have yielded. These conclusions are based on the computed anchor bolt uplift from the average strength limit state racking force, and the geometry at the base of the wall, as tabulated in Table 6. As such, the effects from using ASTM A307 anchor bolts with the wall and hold-down configurations tested here are not accurately reflected by these results, and would certainly be unconservative.

FORCE-DEFLECTION ENVELOPE WITH BILINEAR FORCE-DEFLECTION REPRESENTATION

Coordinates for test panel shear strength and stiffness determination were taken from the force-deflection data at the top of the wall, as specified in the testing protocol (Ref. 1). The cyclical force-deflection results are listed in the appropriate Appendix (x). Refer to Figure x-2 of Appendices A through M for plots of the bilinear force-deflection representation by sample. A tabulated summary of the plywood shear panel configuration, and bilinear coordinates for the positive and negative testing cycles is shown in Table 8.

The absolute average of the bilinear deflection and force coordinates (average of positive and negative cycles) based on the testing are shown in Table 5. Refer to Figure x-3 of Appendices A through M for plots of the absolute average bilinear force-deflection representation by sample.

AVERAGE GROUP SHEAR STRENGTH AND SHEAR MODULUS

Test data used to develop the plywood panel shear strength and stiffness is listed in the appropriate Appendix (x). Refer to Figure x-2 of Appendices A through M for plots of the group average bilinear force-deflection data. A summary of the effective shear stiffness (G') and shear strength of each test panel at the yield and ultimate limit states, as well as the calculated average of the positive and negative cycles each group, is presented in Table 8.

The effective shear stiffness (G') and shear strength of each test panel at the yield and ultimate limit states, as well as the calculated absolute average for each group (average of positive and negative cycles), is shown in Table 5. Refer to Figure x-3 of Appendices A through M for plots of the group average bilinear force-deflection data from which the absolute average for G' was developed.

CONCLUSIONS AND RECOMMENDATIONS

1. Based on the observed behavior of the test panels, the common engineering design practice of neglecting hold-down end-post eccentricity for design of sheathed plywood shear walls appears appropriate, limited by the following caveats:

   - The findings apply to single-story walls in conformance with the UBC. No cyclical load testing of two-story walls was performed to substantiate the additional overturning effects that might occur on stacked (multi-story) walls
   - The load duration factor for both seismic and wind design of end-posts should be limited to $C_D = 1.33$
   - Allowable tension stresses should be considered using the net end-post section (gross area – area of bolt holes and shear plates)
   - Compression perpendicular-to-the-grain of the sill plate should be checked, and a larger end-post selected if required. Based on the observed performance of the sills, use of 73% of the allowable perpendicular to grain compression capacity for deflection critical bearings as specified in the 1997 UBC and 1997 NDS (Section 4.2.6) appears appropriate. Use $C_D = 1.0$
   - The actual wall overturning couple shall be resisted by the hold-down anchor bolt using a reduced arm dimension, L' (base dimension – end-post dimension – hold-down eccentricity), as shown in Figure 4
   - Edge-knots or generally large knots should be prohibited at the lower end of the end-posts, assuming that the hold-downs are installed as in the test panels, at bottom of the end-post. A knothole limitation over the lower 3-feet of the end post appears reasonable based on the test observations

2. For larger end-posts with larger eccentricities, it may be possible that adding a line of nails along the inside edge of the end-post in the vicinity of the hold-down and down to the sill can mitigate the potential effects of the hold-down anchor-bolt eccentricity. Adding an additional line of nails to restrain end-post bending may or may not be practical from a construction standpoint.

3. Based on the significant contribution of sill crushing to the overall plywood shear wall strength and stiffness, it is strongly recommended that future testing of panels include panels constructed to minimize crushing by bearing the end-post on the foundation, and terminating the sill plate at the end-post. Uplift anchorage for the end-post should be developed with a concentric through-bolted heavy column base (USP KCB46), embedded into the concrete. A figure of a KCB column base from the USP catalog is included in Appendix P. This type of hold-down anchorage would also eliminate the possible consideration for "design of the end-post for combined bending and tension due to eccentricity between the hold-down anchor bolt and the end-post". An additional consideration would be to specify that knots are not permitted within 3-feet from the bottom end of the post.

4. The maximum allowable UBC drift ratio for short-period low-aspect wood structures is 0.025 according to Section 1630.10.2 of the 1997 UBC. All test panels in this testing reached the ultimate shear capacity at drifts less than the code maximum 0.025 (2.5%), with the exception of the Group 8 (HTT 50) samples. Where the ultimate shear panel capacity is reached at drifts exceeding the code maximums, it is recommended that the allowable shear panel capacity as determined based on testing should be proportionately reduced to an allowable

capacity at the maximum drift limit, since higher shear strength cannot be developed without exceeding drift limits.

5. Sill bolts on the 2:1 aspect ratio wall test samples were under-designed based on code requirements, though the effects on the testing results are probably negligible. Possible reasons for the acceptable results of the sill bolts during the tests are the contribution of the hold-down anchor-bolts to sill shear, sliding friction against the testing rail, and the overstrength capacity of the connections. In future testing, it is recommended that sill bolt connections should be designed in accordance with the UBC to resist the full plywood sheathing capacity.

6. It is recommended that anchor bolt material for future plywood sheathed shear wall testing should be of the more readily available and typically used ASTM A307 steel, unless another anchor bolt material is listed by the manufacturer in their design data for use with their hold-down. The use of high-strength bolt material in testing will give misleading and unconservative results with regards to plywood sheathed wall performance, when the more generally specified ASTM A307 machine bolts will probably be used in the field.

7. End-posts utilizing multiple combinations of 2x4 studs mechanically connected together should be avoided.

8. The current ICBO published design values for the tested USP Lumber Connector hold-downs appear adequate for restraint of the one-story cyclic loaded plywood sheathed shear walls tested, provided code deflection limitations are included in the design and construction, and the following items are considered:

   - These tests used high-strength hold-down anchor bolts (current practice is to use ASTM A307 anchor bolts). Use high-strength hold-down anchor bolts or account for the use of A307 anchor bolts in the design.
   - The end-post should be sized for compression perpendicular-to-grain of the sill plate.
   - Compressive deformation of the sill plate at the end-post should be included in the deflection calculations
   - Deformation through the body of the hold-down (i.e. bending at the bearing plates supporting the anchor-bolt and side plates) should be considered in the deflection calculations, using the hold-down deflection results from the testing herein.

LIST OF OBSERVERS

The following observers were present during all or some portions of the testing included in this report:

EQE International, Inc.:
Johnathan Shipp, S.E.
Teresa Castle, S.E.
Todd Erickson, S.E.
Mike Riley

UCI Structures Testing Lab:
Robert Kazanjy, Director

USP Lumber Connectors:
Mike Rhodebeck, P.E.
Tom Kolden, P.E.
Steve Hanek
Steven Duncan
Gary Ditzel
Rich Jacobs

Others:
Tim Timmerman

DEFINITIONS

D/C Demand-to-Capacity Ratio: the ratio of the applied force on an element (demand) vs. the element's calculated strength to resist the force (capacity). The D/C is a measure of an element's acceptability for the applied load. A D/C less than 1.0 indicates that the element strength is acceptable to resist the applied load. A D/C greater than 1.0 indicates that the element is overstressed by the applied load.
FME First Major Event
LVDT Linear Variable Displacement Transducer
SLS Strength Limit State (ultimate)
YLS Yield Limit State

REFERENCES

1. "Standard Method of Cyclic (Reversed) Load Test for Shear Resistance of Framed Walls for Buildings", Structural Engineers Association of Southern California (SEAOSC), Revised September 9, 1997.

2. Uniform Building Code (UBC), 1997 Edition, International Conference of Building Officials, 1997.

3. National Design Specification for Wood Construction (NDS), 1997 Edition, American Forest & Paper Association, August 7, 1997.

4. "Preliminary Testing of Wood Structural Panel Shear Walls Under Cyclic (Reversed) Loading" APA Report 158, American Plywood Association, 1998.

5. "City of LA Light Framed Shear Wall Research Project", data from testing performed at UCI, May 1999.

6. Uniform Building Code (UBC), 1994 Edition, International Conference of Building Officials, 1994.

7. National Design Specification for Wood Construction (NDS), Revised 1991 Edition, American Forest & Paper Association, October 16, 1992.

TABLE 1 - PLYWOOD SHEAR WALL TEST PANEL SPECIMEN CONFIGURATION

USP Group Designation	Number of Samples Tested for Group	Plywood Shear Wall and End-Post Specifications													USP Hold-Down Hardware Specifications							
																	Bolts /Nails			Anchor Bolts		
		Sides Sheathed	STRUC I Plywood Thickness	Common Nail Size	Common Nail Spacing EN / FN		1997 UBC Allowable Shear Capacity, lb/ft-wall	UBC Allowable Shear Capacity, lb	Aspect Ratio, h/L	Panel Length (ft)	Sill Bolt No./Diameter		1997 UBC Sill Bolt ASD Shear Capacity (Mode III&IV C_D =1.6)	Nom. Std. & Better End Post Size	**USP Lumber Connectors Hold-Down Device**	Seismic HD Capacity (USP Tech. Bulletin for the 1997 UBC)	Hold-Down to Post Connection No. Bolts/Nails & Diam./Pennyweight		Bolt End Distance	A.B. Diameter	Post A.B. Offset	Eccentricity from C.L. of End-Post Used
1	2	1	3/8	8d	4	12	430	*3,440*	1	8	4	5/8	*7,160*	4x4	**TD 2**	2,860	2	5/8	4 1/2	5/8	1 1/2	3 1/4
2	2	1	15/32	10d	4	12	510	*4,080*	1	8	4	5/8	*7,160*	4x4	**TD 5**	4,090	2	3/4	5 1/4	3/4	2 1/8	3 7/8
3	2	2	15/32	8d	3	12	1,100	*4,400*	2	4	2	5/8	***3,580***	4x4	**TD 9**	8,435	3	1	7	1 1/8	2 1/8	3 7/8
4	2	2	15/32	10d	2	12	1,740	*6,960*	2	4	2	5/8	***3,580***	4x6	**TD 12**	13,260	4	1	7	1 1/8	2 1/8	4 7/8
5	2	1	3/8	8d	4	12	430	*3,440*	1	8	4	5/8	*7,160*	4x4	**HTT 16 (10d)**	3,190	18	10d	Nails	5/8	1 3/8	3 1/8
6	2	1	15/32	10d	2	12	870	*6,960*	1	8	4	5/8	*7,160*	4x4	**HTT 22 (10d)**	5,370	32	10d	Nails	5/8	1 3/8	3 1/8
7	2	2	15/32	8d	3	12	1,100	*4,400*	2	4	2	5/8	***3,580***	4x4	**HTT 30 (16d)**	8,015	36	16d	Nails	7/8	1 3/8	3 1/8
8	2	2	15/32	10d	2	12	1,740	*6,960*	2	4	2	5/8	***3,580***	4x6	**HTT 50 (16d)**	9,810	56	16d	Nails	7/8	1 3/8	4 1/8
9	2	1	15/32	10d	2	12	870	*6,960*	1	8	4	5/8	*7,160*	4x4	**MTS 27B (16d)**	4,635	24	16d	Nails	3/4	1 5/8	3 3/8
10	2	1	15/32	10d	4	12	510	*4,080*	1	8	4	5/8	*7,160*	4x4	**ADS 5**	4,025	2	3/4	5 1/4	3/4	2 1/16	3 7/8
11	2	1	15/32	10d	3	12	665	*5,320*	1	8	4	5/8	*7,160*	4x4	**TDX 6**	5,100	2	7/8	6 1/8	7/8	2	3 3/4
12	2	2	15/32	10d	3	12	1,330	*5,320*	2	4	2	5/8	***3,580***	4x6	**TDX 10**	10,380	4	7/8	6 1/8	7/8	2	4 3/4
13	2	2	15/32	10d	2	12	1,740	*6,960*	2	4	2	5/8	***3,580***	4x6	**ADS 14**	13,570	4	1	7	1	2 1/8	4 7/8
14	1	2	15/32	10d	2	12	1,740	*6,960*	2	4	2	5/8	***3,580***	4x6	**SHD 7 [1]**	7,608	2	3/4	6 1/2	7/8	1 1/2	4 1/4

NOTES: 1. SHD 7 provided and developed by Ben Schmid. SHD 7 hold-down capacity based on capacity of 2-2 5/8" diameter shear plates at the end-post.
2. All sheathing is APA rated STR I plywood of the thickness spec'd.
3. 15/32" plywood is 4-ply, 3/8" plywood is 3-ply
4. All framing lumber is DF-L, untreated.
5. Wall bottom sill plates are 3x4's, and center studs on 8' long walls are 3x4's, No. 2 & Better.
6. Framing members are 16" on center max.
7. Moisture content of framing lumber is 19% or less
8. All UNITS: in, lb, U.N.O.

TABLE 2 - PLYWOOD SHEAR WALL AND HOLD-DOWN DESIGN/STRENGTH SUMARY

USP Group	Plywood Shear Wall and End-Post Specifications											Hold-Down Hardware Specifications									Average Results from Testing L' = L - post dim - HD eccentricity								
															Bolts /Nails			Anchor Bolts											
	Sides Sheathed	Plywood Thickness	Common Nail Size	Nail Spacing		UBC Shear Capacity, lf/ft-wall	UBC Shear Capacity, lb	Aspect Ratio, h/L	Panel Length (ft)	HD Uplift @ Wall Shear Capacity	Nom. End Post Size	USP Hold-Down Device	Seismic HD Capacity (USP Tech. Bulletin for the **1997 UBC**)	HD Design D/C	Bolt Diameter or Nail Pennyweight	No. Connectors	Bolt End Distance	A.B. Diameter	Post A.B. Offset	Eccentricity from C.L. of End-Post	YLS Racking Force	SLS Racking Force	L'/L	YLS HD Tension Based on L'	SLS HD Tension Based on L'	YLS Shear Overstrength	SLS Shear Overstrength	HD D/C Ratio, YLS	HD D/C Ratio, SLS
1	1	3/8	8d	4	12	430	3,440	1	8	3,440	4x4	**TD 2**	**2,860**	1.20	5/8	2	4 1/2	5/8	1 1/2	3.25	4862	6309	0.93	5230	6786	1.41	1.83	1.83	**2.37**
5	1	3/8	8d	4	12	430	3,440	1	8	3,440	4x4	**HTT 16 (10d)**	**3,190**	1.08	10d	18	Nails	5/8	1 3/8	3.13	4794	6231	0.93	5149	6693	1.39	1.81	1.61	2.10
2	1	15/32	10d	4	12	510	4,080	1	8	4,080	4x4	**TD 5**	**4,090**	1.00	3/4	2	5 1/4	3/4	2 1/8	3.88	5571	8907	0.92	6035	9649	1.37	2.18	1.48	**2.36**
10	1	15/32	10d	4	12	510	4,080	1	8	4,080	4x4	**ADS 5**	**4,025**	1.01	3/4	2	5 1/4	3/4	2 1/16	3.81	5620	8294	0.92	6084	8978	1.38	2.03	1.51	**2.23**
6	1	15/32	10d	2	12	870	6,960	1	8	6,960	4x4	**HTT 22 (10d)**	**5,370**	1.30	10d	32	Nails	5/8	1 3/8	3.13	9357	14165	0.93	10051	15215	1.34	2.04	1.87	**2.83**
9	1	15/32	10d	2	12	870	6,960	1	8	6,960	4x4	**MTS 27B (16d)**	**4,635**	1.50	16d	24	Nails	3/4	1 5/8	3.38	9554	14298	0.93	10291	15401	1.37	2.05	2.22	**3.32**
11	1	15/32	10d	3	12	665	5,320	1	8	5,320	4x4	**TDX 6**	**5,100**	1.04	7/8	2	6 1/8	7/8	2	3.75	7686	11526	0.92	8314	12467	1.44	2.17	1.63	**2.44**
3B	2	15/32	8d	3	12	1,100	4,400	2	4	8,800	4x4	**TD 9**	**8,435**	1.04	1	3	7	1 1/8	2 1/8	3.88	4851	7085	0.85	11463	16742	**1.10**	**1.61**	1.36	1.98
7	2	15/32	8d	3	12	1,100	4,400	2	4	8,800	4x4	**HTT 30 (16d)**	**8,015**	1.10	16d	36	Nails	7/8	1 3/8	3.13	5472	8111	0.86	12696	18820	1.24	1.84	1.58	**2.35**
12	2	15/32	10d	3	12	1,330	5,320	2	4	10,640	4x6	**TDX 10**	**10,380**		7/8	4	6 1/8	7/8	2	4.75	3873	7758	0.83	9849	19729	**0.73**	1.46	0.95	1.90
4	2	15/32	10d	2	12	1,740	6,960	2	4	13,920	4x6	**TD 12**	**13,260**	1.05	1	4	7	1 1/8	2 1/8	4.88	8167	10745	0.83	20837	27415	1.17	1.54	1.57	2.07
8	2	15/32	10d	2	12	1,740	6,960	2	4	13,920	4x6	**HTT 50 (16d)**	**9,810**	1.42	16d	56	Nails	7/8	1 3/8	4.13	8276	10956	0.84	20702	27408	1.19	1.57	2.11	**2.79**
13	2	15/32	10d	2	12	1,740	6,960	2	4	13,920	4x6	**ADS 14**	**13,570**	1.03	1	4	7	1	2 1/8	4.88	8251	10826	0.83	21053	27622	1.19	1.56	1.55	2.04
14	2	15/32	10d	2	12	1,740	6,960	2	4	13,920	4x6	**SHD 7** [1]	**7,608**	1.83	3/4	2	6 1/2	7/8	1 1/2	4.25	9143	10806	0.84	22948	27122	1.31	1.55	3.02	**3.57**

NOTES: 1. SHD 7 provided and developed by Ben Schmid. SHD 7 hold-down capacity based on capacity of 2-2 5/8" diameter shear plates at the end-post.
2. All sheathing is APA rated STR I plywood of the thickness spec'd.
3. 15/32" plywood is 4-ply, 3/8" plywood is 3-ply
4. All framing lumber is DF-L, untreated.
5. Wall bottom sill plates are 3x4's, and center studs on 8' long walls are 3x4's, No. 2 & Better.
6. Framing members are 16" on center max.
7. Moisture content of framing lumber is 19% or less
8. All UNITS: in, lb, U.N.O.
9. Complete end-post fracture at a knot-hole near the HD occurred in the Group 3A sample. Only the "B" sample results are reported here.

TABLE 3 - PLYWOOD SHEATHED SHEAR WALL END-POST DESIGN SUMMARY

USP Group	Plywood Shear Wall Specifications [2,3,4,5,6,8]										Hold-Down Hardware Specifications									(Seismic Load Duration Factor, C_D = 1.33)									
														Bolts /Nails			Anchor Bolts												
	Sides Sheathed	Plywood Thickness	Common Nail Size	Nail Spacing		**1997 UBC Shear Capacity, lf/ft-wall**	1997 UBC Shear Capacity, lb	Aspect Ratio, h/L	Panel Length (ft)	HD Uplift @ Wall Shear Capacity [7]	USP Hold-Down Device	Seismic HD Capacity (USP Tech. Bulletin for the *1997 UBC*)	HD Design D/C	**Bolt Diameter or Nail Pennyweight**	No. Connectors	Bolt End Distance	A.B. Diameter	Post A.B. Offset	Eccentricity from C.L. of End-Post	**Nominal End Post Dimensions [9,10]**	Bearing Stress Perp.-to-Grain, psi	Sill Bearing D/C F_{cx}' =0.73x625	End-Post Net Tension Area [1]	End-Post Design Tension Stress, psi	Allowable Tension $F_t' = F_tC_DC_F$ [9,10]	End-Post D/C, Tension Only	*End-Post Eccentric Bend'g Stress, psi [11]*	*Allowable Bending $F_b' = F_bC_DC_F$ [9,10]*	*End-Post D/C, Tens. & Bending Combined [11]*
1	1	3/8	8d	4	12	430	3,440	1	8	3,440	TD 2	2,860	1.20	5/8	2	4 1/2	5/8	1 1/2	3.25	**4x4**	281	0.62	9.84	349	500	0.70	*1,946*	*733*	***3.35***
5	1	3/8	8d	4	12	430	3,440	1	8	3,440	HTT 16 (10d)	3,190	1.08	10d	18	Nails	5/8	1 3/8	3.13	**4x4**	281	0.62	12.25	281	500	0.56	*1,503*	*733*	***2.61***
2	1	15/32	10d	4	12	510	4,080	1	8	4,080	TD 5	4,090	1.00	3/4	2	5 1/4	3/4	2 1/8	3.88	**4x4**	333	0.73	9.41	434	500	0.87	*2,880*	*733*	***4.79***
10	1	15/32	10d	4	12	510	4,080	1	8	4,080	ADS 5	4,025	1.01	3/4	2	5 1/4	3/4	2 1/16	3.81	**4x4**	333	0.73	9.41	434	500	0.87	*2,833*	*733*	***4.73***
6	1	15/32	10d	2	12	870	6,960	1	8	6,960	HTT 22 (10d)	5,370	1.30	10d	32	Nails	5/8	1 3/8	3.13	**4x4**	568	**1.25**	12.25	568	500	**1.14**	*3,042*	*733*	***5.28***
9	1	15/32	10d	2	12	870	6,960	1	8	6,960	MTS 27B (16d)	4,635	1.50	16d	24	Nails	3/4	1 5/8	3.38	**4x4**	568	**1.25**	12.25	568	500	**1.14**	*3,285*	*733*	***5.62***
11	1	15/32	10d	3	12	665	5,320	1	8	5,320	TDX 6	5,100	1.04	7/8	2	6 1/8	7/8	2	3.75	**4x4**	434	0.95	8.97	593	500	**1.19**	*3,811*	*733*	***6.38***
3	2	15/32	8d	3	12	1,100	4,400	2	4	8,800	TD 9	8,435	1.04	1	3	7	1 1/8	2 1/8	3.88	**4x4**	718	**1.58**	8.53	1,032	500	**2.06**	*6,848*	*733*	***11.40***
7	2	15/32	8d	3	12	1,100	4,400	2	4	8,800	HTT 30 (16d)	8,015	1.10	16d	36	Nails	7/8	1 3/8	3.13	**4x4**	718	**1.58**	12.25	718	500	**1.44**	*3,846*	*733*	***6.68***
12	2	15/32	10d	3	12	1,330	5,320	2	4	10,640	TDX 10	10,380	1.03	7/8	4	6 1/8	7/8	2	4.75	**4x6**	553	**1.21**	14.09	755	997	0.76	*3,911*	*1,517*	***3.34***
4	2	15/32	10d	2	12	1,740	6,960	2	4	13,920	TD 12	13,260	1.05	1	4	7	1 1/8	2 1/8	4.88	**4x6**	723	**1.59**	13.41	1,038	997	**1.04**	*5,521*	*1,517*	***4.68***
8	2	15/32	10d	2	12	1,740	6,960	2	4	13,920	HTT 50 (16d)	9,810	1.42	16d	56	Nails	7/8	1 3/8	4.13	**4x6**	723	**1.59**	19.25	723	997	0.73	*3,253*	*1,517*	***2.87***
13	2	15/32	10d	2	12	1,740	6,960	2	4	13,920	ADS 14	13,570	1.03	1	4	7	1	2 1/8	4.88	**4x6**	723	**1.59**	13.41	1,038	997	**1.04**	*5,521*	*1,517*	***4.68***
14	2	15/32	10d	2	12	1,740	6,960	2	4	13,920	SHD 7 [1]	7,608	1.83	3/4	2	6 1/2	7/8	1 1/2	4.25	**4x6**	723	**1.59**	13.42	1,037	997	**1.04**	*4,807*	*1,517*	***4.21***

NOTES: 1. SHD 7 provided and developed by Ben Schmid. SHD 7 hold-down capacity based on allowable capacity of 2-2 5/8" diameter shear plates at the end-post.
2. All sheathing is APA rated STR I plywood of the thickness spec'd.
3. 15/32" plywood is 4-ply, 3/8" plywood is 3-ply
4. All framing lumber is DF-L, untreated, 19% or less moisture content.
5. Wall bottom sill plates are 3x4's, and center studs on 8' long walls are 3x4's, No. 2 & Better.
6. Framing members are 16" on center max.
7. End-post and HD uplift force based on overturning about the out-to-out wall base dimension (panel length).
8. All UNITS: in, lb, U.N.O.
9. 4x4 end posts are Std. & Better, F_t = 375, F_b = 550, $C_{Ft} = C_{Fb}$ = 1.0 (per 1991 NDS Table 2A)
10. 4x6 end posts are No. 2 (& Better), F_t = 575, F_b = 875, $C_{Ft} = C_{Fb}$ = 1.3 (per 1991 NDS Table 2A)
11. Section modulus for bending stress determination reduced for nominal dimensions less the area of bolt holes (here, approximately a 20% - 30% reduction)

TABLE 4 - OBSERVED PLYWOOD SHEAR WALL BEHAVIOR DURING TESTING

USP Group Designation	USP Lumber Connectors Hold-Down Device	Structural Observations From Testing [1]																			
		Aspect Ratio, h/L	Avg. YLS Drift, %	Avg. SLS Drift, %	Sample	Plywood Nail Yielding & Withdrawal	Nail Fatigue Fracture/Withdrawal & Nail Head Pop-Off	Plywood Edge Fracture	Plywood Delamination	Significant Sill Plate Slip	Sill Plate Crushing	Notable Yielding in the Base of the HD	Yielding in the HD Strap	Significant HD Slip at the End-Post	Full or Partial End Post Fracture at Knot	End-Post Splitting Along Line of Bolts	End-Post Bending Observed	Center-Post Splitting	Splitting & Separation at Stud End-Nailing	OTHER COMMENTS & OBSERVATIONS
1	**TD 2**	1	0.49	1.53	A B	NY NY	NF NF												X X	1A: Minor yielding in the base plate of the HD
2	**TD 5**	1	0.35	1.50	A B	NY NY	NF NF					HD							X X	2B: Minor yielding in the HD base plate
3	**TD 9**	2	0.61	1.68	A B	NY NY	NF NF				C C				PF		PB PB			3A: complete Rt.end-post fracture at edge knot. Neck-down fracture of pulled-out nail at 5/8" embedment observed.
4	**TD 12**	2	1.01	2.29	A B	NY NY	NF NF				C C						PB PB			4A: deformation at the bottom of the hold-down and side plate warping observed 4B: Nail neck-down failures observed
5	**HTT 16 (10d)**	1	0.49	1.30	A B	NY NY	NF NF	PW				HD HD	HD HD						X X	
6	**HTT 22 (10d)**	1	0.52	1.77	A B	NY NY	NF NF				C	HD HD	HD HD				PB PB	SP	X X	6B: cracking in the end-post Significant yielding in body of HD
7	**HTT 30 (16d)**	2	0.72	1.97	A B	NY NY	NF NF		PW		C C	HD HD					PB PB		X X	7A: full length of sill nails yielded and withdrew @ end of test
8	**HTT 50 (16d)**	2	1.01	2.56	A B	NY NY	NF NF				C C						PB PB		X X	
9	**MTS 27B (16d)**	1	0.59	1.78	A B	NY NY	NF NF					HD HD	HD HD							9B: Nail neck-down failures observed
10	**ADS 5**	1	0.42	1.64	A B	NY NY	NF NF	PW											X X	
11	**TDX 6**	1	0.47	1.61	A B	NY NY	NF NF	PW											X X	
12	**TDX 10**	2	0.46	2.45	A B	NY NY	NH NF	PW	PW		C C				PF		PB PB			12A: partial end-post fracture, permanent dishing of the HD base plate 12B: sill bolts broke, split sill, permanent dishing of the HD base plate
13	**ADS 14**	2	1.15	2.44	A B	NY NY	NF NF	PW PW	 PW		C C						PB PB			
14	**SHD 7 [2]**	2	1.19	2.11	A -	NY	NF				C					PS	PB			End-post split along line of bolted shear plates occurred

NOTES:

1. The above represents noted behavior in the field and in the field notes. Other behavior not noted in the field or in the field notes is not addessed, including behavior deduced from the cyclical data.
2. SHD 7 provided and developed by Ben Schmid. Uses 2-2 5/8" diameter shear plates at the end-post.
3. YLS (Yield Limit State)
4. SLS (Strength Limit State)

TABLE 5 - COMPARISON OF ESTIMATED VS. ACTUAL PLYWOOD SHEAR WALL CYCLICAL ULTIMATE STRENGTH

USP Group	Plywood Shear Wall Specifications (see additional notes below)								Hold-Down Specifications	Bolts /Nails			USP Catalog Anchor Bolt Specifications			Estimated Wall Force-Deflection Properties			Average Properties from All Cycles of Testing (Positive & Negative)								
	No. Sides Sheathed	Plywood Thickness	Common Nail Size	Nail Spacing		Aspect Ratio, h/L	Panel Length (ft)	Nom. End Post Size	USP Hold-Down Device	Bolt Diameter or Nail Pennyweight	No. Connectors	Bolt End Distance	A.B. Diameter	Post Offset	Eccentricity from Centerline of End Post	Est. SLS Uplift (lbs)	Est. SLS Panel Lateral Load (lbs)	Source COLA Group(s) or USP Control Group	YLS Displacement	YLS Racking Force	G' @ YLS, k/in [7]	SLS Displacement	SLS Racking Force	G' @ SLS, k/in [7]	SLS / YLS Displacement Ratio	SLS / YLS Racking Force Ratio	Actual SLS Capacity as % of Estimated Capacity (COLA or USP)
1	1	3/8	8d	4	12	1	8	4x4	TD 2	5/8	2	4 1/2	5/8	1 1/2	3 1/4	7,600	7,600	2,(10,12)	0.47	4862	10,439	1.47	6309	4,303	3.1	1.3	**83%**
5	1	3/8	8d	4	12	1	8	4x4	HTT 16 (10d)	10d	18	Nails	5/8	1 3/8	3 1/8	7,600	7,600	2, 5	0.47	4794	10,157	1.25	6231	4,987	2.6	1.3	**82%**
2	1	15/32	10d	4	12	1	8	4x4	TD 5	3/4	2	5 1/4	3/4	2 1/8	3 7/8	9,144	9,144	4	0.34	5571	16,631	1.44	8907	6,183	4.3	1.6	**97%**
10	1	15/32	10d	4	12	1	8	4x4	ADS 5	3/4	2	5 1/4	3/4	2 1/16	3 13/16	9,144	9,144	4	0.40	5620	14,175	1.57	8294	5,293	4.0	1.5	**91%**
6	1	15/32	10d	2	12	1	8	4x4	HTT 22 (10d)	10d	32	Nails	5/8	1 3/8	3 1/8	15,176	15,176	9, 13-osb	0.50	9357	18,631	1.70	14165	8,354	3.4	1.5	**93%**
9	1	15/32	10d	2	12	1	8	4x4	MTS 27B (16d)	16d	24	Nails	3/4	1 5/8	3 3/8	15,176	15,176	9	0.57	9554	16,724	1.71	14298	8,341	3.0	1.5	**94%**
11	1	15/32	10d	3	12	1	8	4x4	TDX 6	7/8	2	6 1/8	7/8	2	3 3/4	12,192	12,192	EST	0.45	7686	17,061	1.55	11526	7,423	3.4	1.5	**95%**
3	2	15/32	8d	3	12	2	4	4x4	TD 9	1	3	7	1 1/8	2 1/8	3 7/8	20,266	10,133	EST	0.59	4684	16,013	1.61	6696	8,325	2.7	1.4	**66%**
7	2	15/32	8d	3	12	2	4	4x4	HTT 30 (16d)	16d	36	Nails	7/8	1 3/8	3 1/8	20,266	10,133	EST	0.69	5472	15,814	1.89	8111	8,602	2.7	1.5	**80%**
12	2	15/32	10d	3	12	2	4	4x6	TDX 10	7/8	4	6 1/8	7/8	2	4 3/4	20,000	10,000	EST	0.44	3873	17,547	2.35	7757	6,598	5.3	2.0	**78%**
4	2	15/32	10d	2	12	2	4	4x6	TD 12	1	4	7	1 1/8	2 1/8	4 7/8	21,600	10,800	USP14	0.97	8167	16,761	2.20	10745	9,750	2.3	1.3	**99%**
8	2	15/32	10d	2	12	2	4	4x6	HTT 50 (16d)	16d	56	Nails	7/8	1 3/8	4 1/8	21,600	10,800	USP14	0.97	8276	16,980	2.46	10956	8,912	2.5	1.3	**101%**
13	2	15/32	10d	2	12	2	4	4x6	ADS 14	1	4	7	1	2 1/8	4 7/8	21,600	10,800	USP14	1.10	8251	15,029	2.34	10826	9,236	2.1	1.3	**100%**
14	2	15/32	10d	2	12	2	4	4x6	SHD 7 [1]	3/4	2	6 1/2	7/8	1 1/2	4 1/4	21,600	10,800	USP14	1.14	9143	15,978	2.03	10806	10,673	1.8	1.2	**100%**

NOTES:

1. SHD 7 provided and developed by Ben Schmid. Uses 2-2 5/8" diameter shear plates at the end-post.
2. All sheathing is APA rated STR I plywood of the thickness spec'd.
3. Wall bottom sill plates are 3x4's, and center studs on 8' long walls are 3x4's, No. 2 & Better.
4. Framing members are 16" on center max.
5. Moisture content of framing lumber is 19% or less
6. UNITS: in, lb, U.N.O.
7. Effective shear modulus, G' = V/Δ x H/L

TABLE 6 - PLYWOOD SHEAR WALL HOLD-DOWN DEFLECTION SUMARY

		Anchor Bolt Properties for Deflection Computation					Shear Wall Specifications & Performance from Testing								Sample "A" Results [8]								Sample "B" Results [8]							
															Left End Post				Right End Post				Left End Post				Right End Post			
USP Group	USP Hold-Down Device	A.B. Diameter Used ASTM A193 B7	Anchor Bolt Net Tension Area - Test	SLS HD Tension Based on L'	SLS A.B. Stress, ksi (fy = 105 ksi)	Approx. A.B. Length	No. Sides Sheathed	Aspect Ratio, h/L	Panel Length (ft)	Nom. End Post Size	YLS Racking Force	YLS Displacement	SLS Displacement	SLS Racking Force	YLS End-Post Deflection	SLS End-Post Deflection	YLS HD Slip	SLS HD Slip	YLS End-Post Deflection	SLS End-Post Deflection	YLS HD Slip	SLS HD Slip	YLS End-Post Deflection	SLS End-Post Deflection	YLS HD Slip	SLS HD Slip	YLS End-Post Deflection	SLS End-Post Deflection	YLS HD Slip	SLS HD Slip
1	TD 2	0.63	0.226	6786	30.0	10.0	1	1	8	4x4	4862	0.47	1.47	6309	.055	.200	.007	.020	.040	.166	-	-	.042	.127	.011	.020	.027	.179	.007	.020
															-.030	-.060			-.010	-.022			-.005	-.030			-.030	-.015		
5	HTT 16 (10d)	0.63	0.226	6693	29.6	7.5	1	1	8	4x4	4794	0.47	1.25	6231	.067	.158	.011	.021	.072	.142	.014	.027	.061	.198	.009	.033	.054	.217	.008	.023
															-.030	-.062			-.070	-.091				-.016			-.040	-.062		
2	TD 5	0.75	0.334	9649	28.9	10.0	1	1	8	4x4	5571	0.34	1.44	8907	.050	.191	-	-	.081	.272	-	-	.037	.191	.010	.025	.028	.134	.009	.027
															-.008	-.016				-.008			-.017	-.033			-.013	-.026		
10	ADS 5	0.75	0.334	8978	26.9	7.5	1	1	8	4x4	5620	0.40	1.57	8294	.053	.202	.023	.038	.087	.274	.034	.083	.058	.222	-	-	-.055	.295	.016	.030
															-.019	-.033			-.007	-.020			-.040	-.062			-.014	-.017		-.019
6	HTT 22 (10d)	0.63	0.226	15215	**67.3**	7.5	1	1	8	4x4	9357	0.50	1.70	14165	.103	.491	.010	.045	.082	.566	.011	.060	.141	.484	.009	.032	.138	.480	.006	.022
															-.035	-.042			-.010	-.044			-.050	-.119			-.020	-.059		
9	MTS 27B (16d)	0.75	0.334	15401	**46.1**	7.5	1	1	8	4x4	9554	0.57	1.71	14298	.166	.476	.032	.076	.111	.457	.016	.065	.144	.442	.010	.031	.123	.457	.009	.033
															-.023	-.073			-.065	-.100			-.098	-.157			-.078	-.115		
11	TDX 6	0.88	0.462	12467	27.0	7.5	1	1	8	4x4	7686	0.45	1.55	11526	.069	.185	.025	.090	.064	.197	.020	.080	.038	.109	.015	.025	.044	.139	.020	.055
															-.032	-.051			-.045	-.071			-.020	-.034			-.047	-.081		
3B [3]	TD 9	1.00	0.606	16742	27.6	10.0	2	2	4	4x4	4684	0.59	1.61	6696									.077	.167	.050	.012	.077	.170	.040	.090
																							-.017	-.160			-.068	-.096		
7	HTT 30 (16d)	0.88	0.462	18820	**40.7**	7.5	2	2	4	4x4	5472	0.69	1.89	8111	.094	.335	.017	.042	.101	.304	.030	.065	.203	.443	.012	.030	-	-	.012	.033
															-.021	-.066			-.017	-.033			-.051	-.117			-	-		
12	TDX 10	0.88	0.462	19729	**42.7**	7.5	2	2	4	4x6	3873	0.44	2.35	7757	.082	.514	-	.100	.044	.472	-	.100	.068	.483	-	-	.081	.231	.043	.100
															-.016	-.086			-.020	-.036			-.020	-.036			-.106	-.288		
4	TD 12	1.00	0.606	27415	**45.2**	9.5	2	2	4	4x6	8167	0.97	2.20	10745	.106	.213	.048	.100	.126	.184	-	-	.083	.235	-	-	.093	.231	.043	.100
															-.083	-.166			-.094	-.222			-.090	-.245			-.106	-.288		
8	HTT 50 (16d)	0.88	0.462	27408	**59.3**	7.5	2	2	4	4x6	8276	0.97	2.46	10956	.167	.458	.018	.039	.166	.433	.021	.042	.169	.607	.016	.039	.183	.457	.014	.035
															.-.061	-.091			-.033	-.100			-.047	-.120			-.027	-.111		
13	ADS 14	1.00	0.606	27622	**45.6**	9.5	2	2	4	4x6	8251	1.10	2.34	10826	.147	.298	.020	.080	.148	.365	.021	.085	.190	.368	.044	.172	.174	.318	.044	.077
															-.040	-.057			-.052	-.078			-.120	-.248			-.076	-.143		
14	SHD 7 [1]	0.88	0.462	27122	**58.7**	9.0	2	2	4	4x6	9143	1.14	2.03	10806	.110	.209	.074	.160	.113	.168	.067	.110								
															-.081	-.145			-.072	-.221										

NOTES:
1. SHD 7 provided and developed by Ben Schmid. Uses 2-2 5/8" diameter shear plates at the end-post.
2. All UNITS: in, lb, U.N.O.
3. Complete end-post fracture at a knot-hole near the HD occurred in the Group 3A sample. Only the "B" sample results are reported here.
4. YLS (Yield Limit State)
5. SLS (Strength Limit State)
6. Additional unmeasured sources of top of wall deflection (plywood panel deformation & nail yielding; sill crushing) are not included in this comparison.
7. Includes both elastic and inelastic deformations.
8. Negative numbers indicate "bearing deformations" and/or crushing of the sill plates.

TABLE 6A - PLYWOOD SHEAR WALL HOLD-DOWN DEFLECTION SUMARY

USP Group	USP Hold-Down Device	Average End-Post Hold-Down Properties for Samples "A" & "B" [8]								YLS Total End-Post Deflection	SLS Total End-Post Deflection	YLS HD-Post Slip	SLS HD-Post Slip	YLS Anchor Bolt Deflection (By calculation)	SLS Anchor Bolt Deflection (By calculation)	YLS HD Deflection (Difference) [7]	SLS HD Deflection (Difference) [7]	HD Deflection/Panel Deflection x h/L [6]							
		YLS End-Post Deflection	SLS End-Post Deflection	YLS HD Slip	SLS HD Slip	End-Post K' @ YLS, k/in	End-Post K' @ SLS, k/in	HD Slip K' @ YLS, k/in	HD Slip K' @ SLS, k/in									**Total End-Post Uplift vs. Wall Deflection, YLS [6]**	**Total End-Post Uplift vs. Wall Deflection, SLS [6]**	**YLS HD Slip vs. Wall Deflection Ratio**	**SLS HD Slip vs. Wall Deflection Ratio**	**YLS A.B. Deflection Ratio**	**SLS A.B. Deflection Ratio**	**YLS HD Deflection vs. Wall Deflection Ratio**	**SLS HD Deflection vs. Wall Deflection Ratio**
1	TD 2	.041	.168	.008	.020	119	29	583	243	.041	.168	.008	.020	.007	.010	.025	.138	**9%**	**11%**	1.8%	1.4%	1.6%	0.7%	**5.4%**	**9.4%**
		-.019	-.032			259	153																		
5	HTT 16 (10d)	.064	.179	.011	.026	75	27	457	184	.064	.179	.011	.026	.005	.007	.048	.146	**14%**	**14%**	2.2%	2.1%	1.2%	0.6%	10.1%	11.7%
		-.047	-.058			103	83																		
2	TD 5	.049	.197	.010	.026	114	28	586	214	.049	.197	.010	.026	.006	.009	.034	.162	**14%**	**14%**	2.8%	1.8%	1.7%	0.6%	9.9%	11.2%
		-.013	-.021			440	269																		
10	ADS 5	.036	.248	.024	.050	157	23	231	112	.036	.248	.024	.050	.004	.006	.007	.191	**9%**	**16%**	6.1%	3.2%	1.1%	0.4%	**1.8%**	**12.2%**
		-.020	-.033			281	170																		
6	HTT 22 (10d)	.116	.505	.009	.040	81	19	1,040	235	.116	.505	.009	.040	.011	.016	.096	.449	**23%**	**30%**	1.8%	2.3%	2.1%	1.0%	**19.3%**	**26.5%**
		-.029	-.066			325	142																		
9	MTS 27B (16d)	.136	.458	.017	.051	70	21	568	186	.136	.458	.017	.051	.007	.011	.112	.396	**24%**	**27%**	3.0%	3.0%	1.3%	0.6%	**19.6%**	**23.1%**
		-.066	-.111			145	86																		
11	TDX 6	.054	.158	.020	.063	143	49	384	123	.054	.158	.020	.063	.004	.006	.029	.089	**12%**	**10%**	4.4%	4.0%	1.0%	0.4%	6.5%	5.7%
		-.036	-.059			213	130																		
3B [3]	TD 9	.077	.169	.045	.051	122	56	208	184	.077	.169	.045	.051	.003	.004	.029	.114	**26%**	**21%**	15.3%	6.3%	0.9%	0.5%	9.9%	14.1%
		-.043	-.128			220	73																		
7	HTT 30 (16d)	.133	.361	.018	.043	82	30	617	257	.133	.361	.018	.043	.003	.005	.112	.314	**38%**	**38%**	5.1%	4.5%	0.9%	0.5%	32.4%	33.3%
		-.030	-.072			369	152																		
12	TDX 10	.069	.425	.043	.100	113	18	180	77	.069	.425	.043	.100	.002	.004	.024	.321	**31%**	**36%**	19.5%	8.5%	1.0%	0.4%	**10.7%**	**27.3%**
		-.041	-.112			191	69																		
4	TD 12	.102	.216	.046	.100	160	76	359	163	.102	.216	.046	.100	.004	.006	.052	.110	**21%**	**20%**	9.4%	9.1%	0.9%	0.5%	10.7%	10.0%
		-.093	-.230			175	71																		
8	HTT 50 (16d)	.171	.489	.017	.039	97	34	959	427	.171	.489	.017	.039	.005	.006	.149	.444	**35%**	**40%**	3.6%	3.2%	1.0%	0.5%	**30.8%**	**36.1%**
		-.036	-.106			464	157																		
13	ADS 14	.165	.337	.032	.104	100	49	512	159	.165	.337	.032	.104	.004	.006	.128	.228	**30%**	**29%**	5.9%	8.8%	0.8%	0.5%	23.3%	19.4%
		-.072	-.132			229	125																		
14	SHD 7 [1]	.112	.189	.071	.135	164	97	259	135	.112	.189	.071	.135	.006	.007	.035	.046	**20%**	**19%**	12.4%	13.3%	1.1%	0.7%	6.1%	4.6%
		-.077	-.183			239	100																		

NOTES:
1. SHD 7 provided and developed by Ben Schmid. Uses 2-2 5/8" diameter shear plates at the end-post.
2. All UNITS: in, lb, U.N.O.
3. Complete end-post fracture at a knot-hole near the HD occurred in the Group 3A sample. Only the "B" sample results are reported here.
4. YLS (Yield Limit State)
5. SLS (Strength Limit State)
6. The difference between the percent top of wall deflections due to the the total end-post slip and deflormation, and full (100%) top of wall delfection is due to additional unmeasured sources of top of wall deflection: plywood panel deformation & nail yielding; sill crushing.
7. Includes both elastic and inelastic deformations in the body of the hold-down.
8. Negative numbers indicate "bearing deformations" and/or crushing of the sill plates.

TABLE 7 - PLYWOOD SHEAR WALL HOLD-DOWN STIFFNESS SUMARY

USP Group	USP Hold-Down Device	Shear Wall Specifications & Strength from Testing										Hold-Down & Hold-Down Connection Stiffness Comparison [7] Based on Estimated HD Tension Force Using L' Dimension [6]									Seismic HD D/C from Design (Capacity from USP Tech. Bulletin for the **1997 UBC**)
		Sides Sheathed	Aspect Ratio, h/L	Panel Length (ft)	Nom. End Post Size	YLS Racking Force	YLS HD Tension Based on L'	YLS Displacement	SLS Racking Force	SLS HD Tension Based on L'	SLS Displacement	Net HD/Connection Deflection @ YLS	Het HD/Connection Deflection @ SLS	Net HD/Connection Stiffness @ YLS, k/in	Net HD/Connection Stiffness @ SLS, k/in	Manuf. Allowable HD Capacity	Manuf. Deflection @ Allowable Load	USP HD Stiffness @ Design Force, ksi	Totla YLS vs. Design Stiffness Ratio	Total SLS vs. Design Stiffness Ratio	
1	TD 2	1	1	8	4x4	4,862	5,230	0.47	6,309	6,786	1.47	0.034	0.158	156	**43**	2,860	0.069	**41**	*3.76*	*1.03*	1.20
5	HTT 16 (10d)	1	1	8	4x4	4,794	5,149	0.47	6,231	6,693	1.25	0.058	0.172	89	**39**	3,190	0.122	**26**	*3.39*	*1.49*	1.08
2	TD 5	1	1	8	4x4	5,571	6,035	0.34	8,907	9,649	1.44	0.043	0.188	140	**51**	4,090	0.101	**40**	*3.45*	*1.27*	1.00
10	ADS 5	1	1	8	4x4	5,620	6,084	0.40	8,294	8,978	1.57	0.031	0.242	194	**37**	4,025	-	**-**	-	-	1.01
6	HTT 22 (10d)	1	1	8	4x4	9,357	10,051	0.50	14,165	15,215	1.70	0.105	0.489	95	**31**	5,370	0.125	**43**	*2.22*	***0.72***	**1.30**
9	MTS 27B (16d)	1	1	8	4x4	9,554	10,291	0.57	14,298	15,401	1.71	0.129	0.447	80	**34**	4,635	0.112	**41**	*1.93*	***0.83***	**1.50**
11	TDX 6	1	1	8	4x4	7,686	8,314	0.45	11,526	12,467	1.55	0.049	0.151	168	**83**	5,100	0.051	**100**	*1.68*	***0.83***	1.04
3B [3]	TD 9	2	2	4	4x4	4,684	11,463	0.59	6,696	16,742	1.61	0.074	0.165	154	**102**	8,435	0.060	**141**	*1.10*	*0.72*	1.04
7	HTT 30 (16d)	2	2	4	4x4	5,472	12,696	0.69	8,111	18,820	1.89	0.130	0.356	98	**53**	8,015	0.121	**66**	*1.48*	***0.80***	**1.10**
12	TDX 10	2	2	4	4x6	3,873	9,849	0.44	7,757	19,729	2.35	0.067	0.421	148	**47**	10,380	0.095	**109**	*1.35*	***0.43***	
4	TD 12	2	2	4	4x6	8,167	20,837	0.97	10,745	27,415	2.20	0.098	0.210	214	**131**	13,260	0.113	**117**	*1.82*	*1.11*	1.05
8	HTT 50 (16d)	2	2	4	4x6	8,276	20,702	0.97	10,956	27,408	2.46	0.167	0.483	124	**57**	9,810	0.125	**78**	*1.58*	***0.72***	**1.42**
13	ADS 14	2	2	4	4x6	8,251	21,053	1.10	10,826	27,622	2.34	0.160	0.331	131	**83**	13,570	0.113	**120**	*1.09*	***0.69***	1.03
14	SHD 7	2	2	4	4x6	9,143	22,948	1.14	10,806	27,122	2.03	0.105	0.181	218	**150**	7,608	-	**-**	-	-	1.83

NOTES:

1. SHD 7 provided and developed by Ben Schmid. Uses 2-2 5/8" diameter shear plates at the end-post.
2. All UNITS: in, lb, U.N.O.
3. Complete end-post fracture at a knot-hole near the HD occurred in the Group 3A sample. Only the "B" sample results are reported here.
4. YLS (Yield Limit State)
5. SLS (Strength Limit State)
6. Refer to Table 2 for L'/L ratio
7. The Net HD/Connection Stiffness is based on the calculated HD body and end-post slip deflections from testing (Total end-post deflection less the calculated A.B. deflection)

TABLE 8 - BILINEAR PLYWOOD SHEAR WALL FORCE-DEFLECTION PROPERTIES AND G' FROM CYCLICAL TESTING

USP Group	Plywood Panel Specifications								USP Hold-Down Device	Sample "A" Results Positive & Negative Cycles				Sample "B" Results Positive & Negative Cycles				Average Properties for Samples "A" & "B" Positive & Negative Cycles [2,3,4,5,6]							
	No. Sides Sheathed	Plywood Thickness	Common Nail Size	Nail Spacing		Aspect Ratio, h/L	Panel Length (ft)	Nom. End Post Size		YLS Displacement	YLS Racking Force	SLS Displacement	SLS Racking Force	YLS Displacement	YLS Racking Force	SLS Displacement	SLS Racking Force	YLS Displacement	YLS Racking Force	SLS Displacement	SLS Racking Force	**YLS Capacity, lb/ft-wall**	**SLS Capacity, lb/ft-wall**	**G' @ YLS, k/in**	**G' @ SLS, k/in**
1	1	3/8	8d	4	12	1	8	4x4	TD 2	0.49	5136	1.38	6596	0.45	4731	1.36	6024	0.47	4933	1.37	6310	617	789	10,530	4,596
										-0.47	-4582	-1.57	-5834	-0.46	-4999	-1.54	-6780	-0.46	-4791	-1.56	-6307	-599	-788	10,347	4,046
5	1	3/8	8d	4	12	1	8	4x4	HTT 16 (10d)	0.49	4808	0.97	6113	0.47	5086	1.35	6463	0.48	4947	1.16	6288	618	786	10,371	5,409
										-0.49	-4273	-1.15	-5565	-0.45	-5010	-1.52	-6784	-0.47	-4641	-1.34	-6174	-580	-772	9,938	4,620
2	1	15/32	10d	4	12	1	8	4x4	TD 5	0.39	6094	1.56	8856	0.37	6023	1.26	8452	0.38	6059	1.41	8654	757	1082	15,902	6,150
										-0.16	-3645	-1.49	-9046	-0.42	-6523	-1.46	-9276	-0.29	-5084	-1.47	-9161	-636	-1145	17,592	6,213
10	1	15/32	10d	4	12	1	8	4x4	ADS 5	0.39	5765	1.65	8112	0.39	5898	1.29	8531	0.39	5832	1.47	8321	729	1040	14,895	5,665
										-0.37	-4995	-1.85	-8157	-0.43	-5823	-1.48	-8378	-0.40	-5409	-1.67	-8268	-676	-1033	13,472	4,965
6	1	15/32	10d	2	12	1	8	4x4	HTT 22 (10d)	0.41	8206	1.59	13500	0.53	10112	1.64	14254	0.47	9159	1.62	13877	1145	1735	19,508	8,593
										-0.53	-9391	-1.93	-14249	-0.54	-9719	-1.62	-14657	-0.54	-9555	-1.78	-14453	-1194	-1807	17,860	8,138
9	1	15/32	10d	2	12	1	8	4x4	MTS 27B (16d)	0.60	9600	1.69	13631	0.56	9744	1.63	14527	0.58	9672	1.66	14079	1209	1760	16,604	8,484
										-0.43	-8593	-1.67	-14276	-0.69	-10278	-1.87	-14757	-0.56	-9436	-1.77	-14517	-1179	-1815	16,850	8,206
11	1	15/32	10d	3	12	1	8	4x4	TDX 6	0.51	8122	1.53	11454	0.46	7635	1.49	11136	0.48	7879	1.51	11295	985	1412	16,312	7,482
										-0.43	-7645	-1.77	-12149	-0.40	-7342	-1.42	-11364	-0.42	-7493	-1.60	-11757	-937	-1470	17,926	7,366
3	2	15/32	8d	3	12	2	4	4x4	TD 9	0.65	5005	2.05	7020	0.61	4721	1.70	7107	0.63	4863	1.88	7063	1216	1766	15,501	7,524
										-0.48	-4027	-0.92	-5592	-0.61	-4981	-1.76	-7064	-0.54	-4504	-1.34	-6328	-1126	-1582	16,606	9,448
7	2	15/32	8d	3	12	2	4	4x4	HTT 30 (16d)	0.59	5464	1.72	7918	0.89	5848	2.27	8247	0.74	5656	2.00	8083	1414	2021	15,225	8,097
										-0.51	-4566	-1.79	-8012	-0.77	-6009	-1.76	-8268	-0.64	-5287	-1.78	-8140	-1322	-2035	16,497	9,169
12	2	15/32	10d	3	12	2	4	4x6	TDX 10	0.31	3403	2.31	7515	0.37	2802	2.78	7883	0.34	3102	2.55	7699	776	1925	18,223	6,045
										-0.48	-4598	-2.30	-7693	-0.60	-4691	-2.01	-7939	-0.54	-4644	-2.16	-7816	-1161	-1954	17,122	7,250
4	2	15/32	10d	2	12	2	4	4x6	TD 12	1.14	8883	2.22	10802	1.09	8755	2.38	11185	1.11	8819	2.30	10993	2205	2748	15,876	9,570
										-0.93	-7706	-2.01	-9950	-0.74	-7323	-2.21	-11042	-0.84	-7514	-2.11	-10496	-1879	-2624	17,933	9,946
8	2	15/32	10d	2	12	2	4	4x6	HTT 50 (16d)	1.16	8650	2.72	11146	1.07	8902	2.63	11267	1.11	8776	2.67	11206	2194	2802	15,749	8,383
										-0.78	-7008	-2.29	-10433	-0.89	-8543	-2.20	-10977	-0.84	-7775	-2.24	-10705	-1944	-2676	18,623	9,541
13	2	15/32	10d	2	12	2	4	4x6	ADS 14	1.15	8531	2.23	11299	1.10	8110	2.64	10910	1.12	8320	2.44	11105	2080	2776	14,831	9,117
										-1.09	-8461	-2.26	-10795	-1.06	-7903	-2.24	-10298	-1.07	-8182	-2.25	-10547	-2045	-2637	15,236	9,365
14	2	15/32	10d	2	12	2	4	4x6	SHD7 [1]	1.12	8708	2.37	10747	-	-	-	-	1.12	8708	2.37	10747	2177	2687	15,606	9,061
										-1.17	-9578	-1.68	-10866	-	-	-	-	-1.17	-9578	-1.68	-10866	-2395	-2716	16,331	12,951

NOTES:

1. SHD 7 provided and developed by Ben Schmid. Uses 2-2 5/8" diameter shear plates at the end-post.
2. All UNITS: in, lb, U.N.O.
3. Negative numbers indicate "bearing deformations" and/or crushing of the sill plates.
4. YLS (Yield Limit State)
5. SLS (Strength Limit State)
6. Effective shear modulus, $G' = V/\Delta \times H/L$