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Test Setup Development for Lateral Loading Experiment of Light-Frame Wood Shearwall

Based on ASTM Standards

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Summary

This report offers requirements and recommendations for developing a standardized test setup for static and cyclic (reversed) load conditions on shear walls of light-frame structures. The emphasis is on the development of a test setup that complies with the requirements prescribed in ASTM standards [1]–[3] for evaluating the shear capacity of a typical section of a framed wall, supported on a rigid foundation and having load applied in the plane of the wall along the edge opposite the rigid support and a direction parallel to it.

The objective is to provide detailed requirements for parts of the test setup to achieve the standardized determination of shear stiffness and strength of any structural light-frame wall configuration used as a shear-wall on a rigid support. Recommendations are also made on specimen fabrication, testing procedures, specimen instrumentation, and preliminary test results documentation.

The project was performed as a comparative study of an 8 ft by 8 ft light wood frame shear wall. The reference specimen in this project utilizes mechanical fasteners (i.e., smooth nails) as prescribed in the construction code, such as the International Building Code (IBC) [4]. Simultaneously, an augmented shear wall system was investigated based on the reference specimen with elastomeric construction adhesives. The reason for involving the adhesive is to provide an alternative to enhance energy absorption against wind and seismic loads compared to the typical mechanical fastener [5], which will be covered comprehensively in the next project report.

1 Introduction

1.1 Shear wall testing apparatus

The shear wall is a structural subassembly that acts as a cantilever/diaphragm to transfer horizontal building loads to the foundation in the form of horizontal shear and an overturning. This practice describes the load frame apparatus used to perform the shear wall experiments. The load frame apparatus consists of a 100 kip (500 kN) vertical actuator and a 22 kip (100 kN) horizontal actuator. Within the projects scope, the horizontal actuator was exclusively employed in the testing to evaluate the shear stiffness, shear strength, and ductility of the vertical elements of lateral force resisting systems. This included applicable shear connections and hold-down connections, under static and cyclic (reversed) load conditions. This is accomplished by anchoring the wall assembly's bottom edge and applying a force to the top edge oriented perpendicular to the wall height dimension and parallel to the wall-length dimension. Wall distortion is restricted to the plane of the unstressed wall. The forces required to rack the wall and the corresponding displacements at each load interval are measured.

The following discussion provides detailed information on the performed design and fabrication actions to develop the infrastructure's facility to ensure that the in-plane loads are applied and measured in a suitable means. Specifically, the horizontal actuator located at Bronco Construction Research Center (BCRC) was affixed to a steel crossbeam. However, it lacked a supporting framework that would render the equipment suitable to conduct tests. Various engineered fixturing designs were drawn, manufactured, and installed. Through adopting the empirical approach, original mechanical designs were modified, and adjustments made to accommodate hard-wired sensors, mitigate the specimen's tortuosity during testing, and verify that repeatable results were obtainable. The initial goal of the shear wall testing program at BCRC was to verify repeatable results based on validation testing. As a supplement to the validation tests, a related and comprehensive load frame/shear wall technical report was necessary to be provided.

The research found significant gaps in mechanical fixturing, types of deployed sensors, test implementation, and standardization of how the test specimens were constructed. During our validation testing, a need to adjust variables was determined, namely the addition of an adhesive in conjunction with nails. Therefore, validation testing outcomes can be utilized to conduct research significantly impacting strengthening shear walls using untraditional construction material.

Regarding ASTM standards for shear wall testing, some key components were initially overlooked to prototype and quickly proved this research hypothesis. The approach was to fabricate an apparatus that allows the testing to be conducted convincingly for a comparative study of shear walls. This approach would have been satisfactory had the process and fixturing been repeatable. However, repeatability and accuracy were not established using the early test setup. The following sections dissect and analyze the failure modes of the early testing setup and document the genesis of the final version of the shear wall testing apparatus at Western Michigan University. The final version of the apparatus provides a reliable, uniform procedure for determining the resistance to racking load provided by the shear wall as commonly employed in building construction.

2 Technical requirements and recommendation

2.1 Constrained actuator induces uplift forces

The current approach's racking load is applied horizontally along the specimen's plane using a double-acting hydraulic actuator with a load cell. The load is distributed along the top of the specimen utilizing a loading beam (see **Figure 1**). The beam used to transfer loads between the hydraulic cylinder and the test specimen is selected to not contribute to the measured racking strength and stiffness. The beam is designed at stiffness less than the permitted maximum stiffness of 330 000 kips-in^2. The selected stiffness corresponds with an HSS 3.5 × 3.5 × 3/8 -in the steel section. The load beam's combined gravity load is applied to the specimen, and the actuator is less than 350 lbs. Some approaches employ a rope or chain attached to an overhead superstructure, which suspends the actuator's weight to remove the test specimen's vertical loading effect.

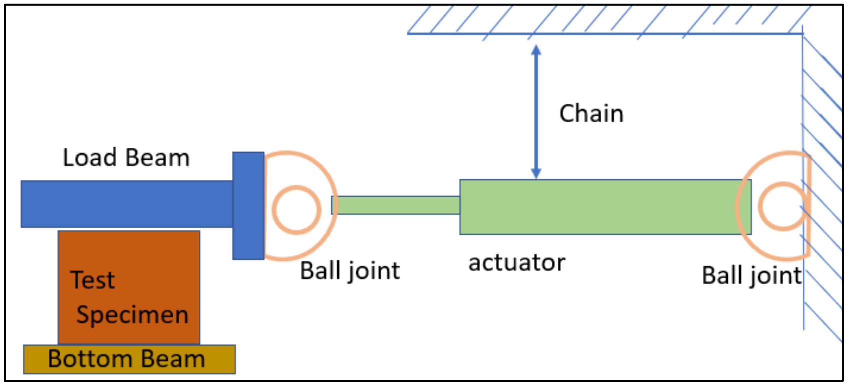


Figure 1: Typical shear wall test setup

Another approach, albeit less common in practice, is to support the actuator and transfer the destructive force to the test sample using a lever arm. The lever arm attached to the strong floor via a hinge joint, and at the other extremity, the lever arm supports the actuator from the bottom via a pivot joint. The pivot arm, which length equals the height of the sample, or 8 feet, is parallel to the studs and pivots in a manner that allows it to remain parallel to the studs as the sample is racked via the hydraulic actuator. The practical implication of the hinge arm method is twofold. Firstly, it mitigates unwanted loading of the test sample by the test setup apparatus and, secondly, guarantees a correct racking behavior of the shear wall system. Referring to the tendency for a wall frame to distort from rectangular to rhomboid under the action of an in-plane force applied parallel to (see **Figure 2**).

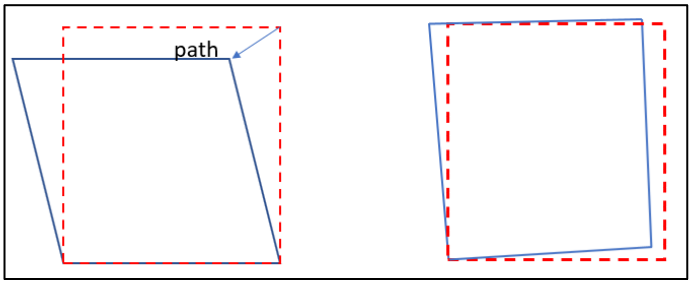


Figure 2: Correct (left) and random (right) racking

Using the chain of mitigating the undesirable vertical loading due to the mass of the test apparatus (actuator and the load beam) was selected due to ease of deployment and a lower cost. In our case, a chain hoist was used to suspend the hydraulic cylinder from the load frame superstructure. In theory, the vertical load is mitigated in this way. However, an undesirable effect was induced by uplifting forces on the test sample and test fixturing.

An upward momentum or displacement vector was observed at the top corner of the specimen (i.e., at the load applied point) when the actuator was constrained by a suspender and the actuator's end attached the load beam. This vector path traces upward, defining an arched path to the shear wall assembly from the top corner as the actuator extends, as shown in **Figure 2**. This type of uplifting behavior is similar to a pendulum system. The suspender (rope or chain) acts as a pendulum arm, swinging the actuator with an undesired vector. In this way, tightening the test frame contributed tremendous uplift forces on the test sample, and worse, the load was transferred to the steel reaction frame, which lacked sufficient stiffness in that particular section along its length (**Figure 3**). The result was a curved bottom steel beam that was attached to the strong floor. As it was designed first, the initial C-channel lacked sufficient stiffness in conjunction with the strong floor anchors, which were positioned on 7-ft centers. Stiffer steel would be needed to span 7-ft to withstand the uplift forces. Therefore, a base plate tube was needed in the new design based on the initial test setup design observations.

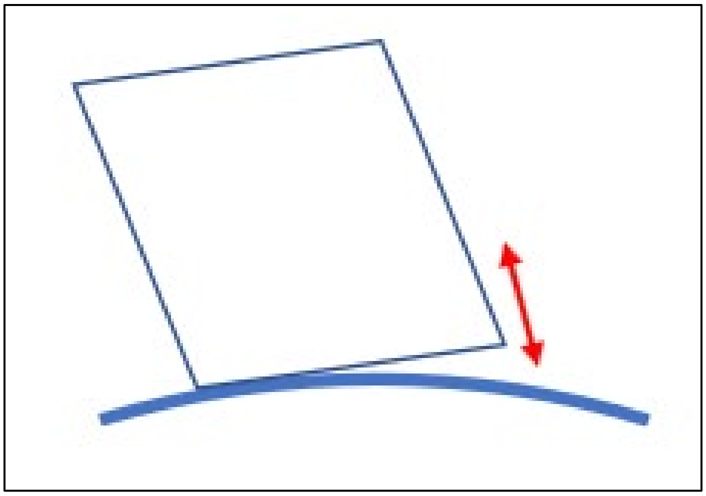


Figure 3: Incorrectly racked wall system and subsequent fixture damage – curved bottom beam

In summary, our findings indicate that suspending the actuator from the reaction frame invalidates the shear wall test, and it is not recommended geometric design. If the shear wall is not allowed to tilt appropriately, the test device or equipment's weight does not exceed the range assigned by ASTM standards in the vertical direction; therefore, the suspension is unnecessary.

2.2 Free Shear Wall Induces Out-of-Plane Behavior

A critical component that was initially excluded from the shear wall testing apparatus design is the top lateral support reaction mechanism (i.e., beams) (see **Figure 5**). The wall test assembly shall be laterally supported along its top with rollers or equivalent means to restrict assembly displacement outside the loading plane. Lateral support rigidity shall not exceed that provided in the actual building construction. Without this support mechanism, the inherent internal stresses accumulated within each test sample produce a highly erratic behavior related to movement, as shown in **Figure 5**. Attempts were made to test an unconstrained shear wall, which produced buckling and twisting of the test specimens as we theorized. Therefore, it was concluded that the test apparatus should support the specimen as necessary to prevent displacement from the specimen's plane, but in-plane displacement shall not be restricted.

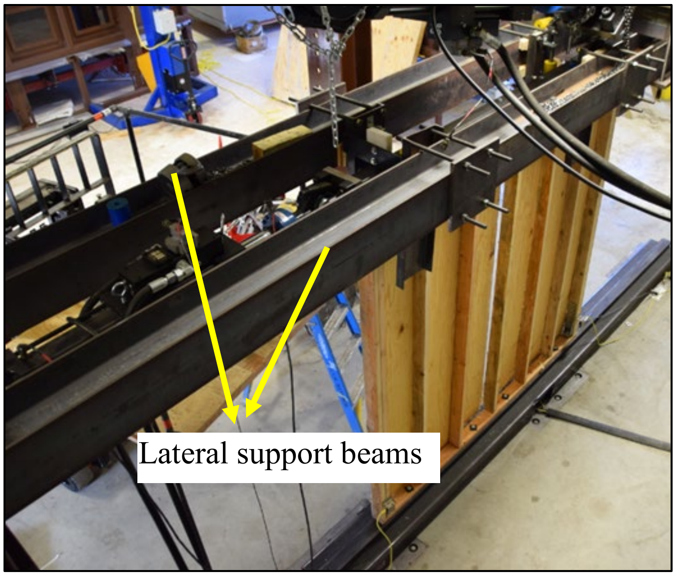


Figure 4: Shear wall test specimen laterally supported by top H-steel beams

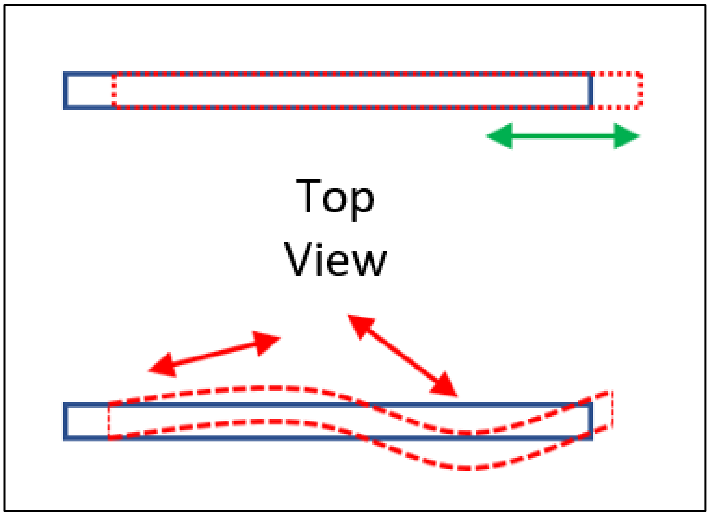


Figure 5: laterally supported shear wall with only in-plane behavior (top) and variable out-of-plane wall behavior in the absence of lateral support (bottom).

In our case, it was spanned the load frame superstructure or the reactionary frame with H-beam sections held in place by frictional plates. This allows the apparatus to be reconfigured or adjusted for various widths of samples of shear walls if desired in the future. The shear wall sample is held captive between two parallel beam sections; these sections feature two urethane rollers on hardened shafts. These rollers engage the load beam and guide the assembly in a smooth and frictionless translation in a single plane (see **Figure 6**).

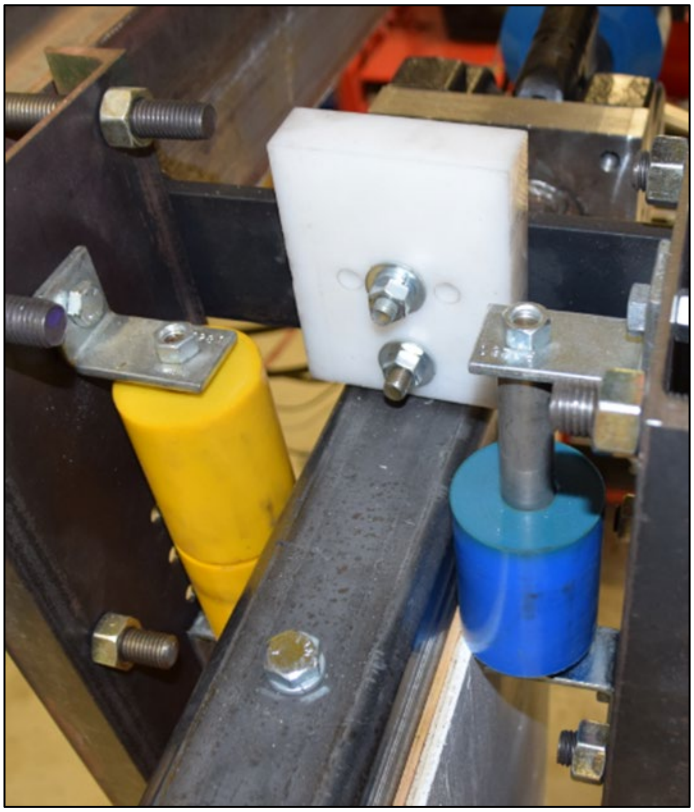


Figure 6: Load Beam engaging the guide roller assembly against the reactionary frame

2.3 Rotationally Constrained Sheathing induces undesirable loads

It is worth noting that some practices have been observed in the literature that utilized the following heuristic design methodology, producing invalid results. When the sheathing is loaded in shear against the wood frame, studs tend to rotate. Therefore, sheathing must freely rotate without bearing on the base fixture, loading fixture, or any other portion of the test frame. However, if interference with other components is present, the loads are transferred from the sheathing into the interfering component. Illustrated in **Figure 7**, the assembly's front view, where during rotation, the corners of the sheathing plunge under the bottom beam and push up above the load beam. Figure 9 shows the side view of the interference.

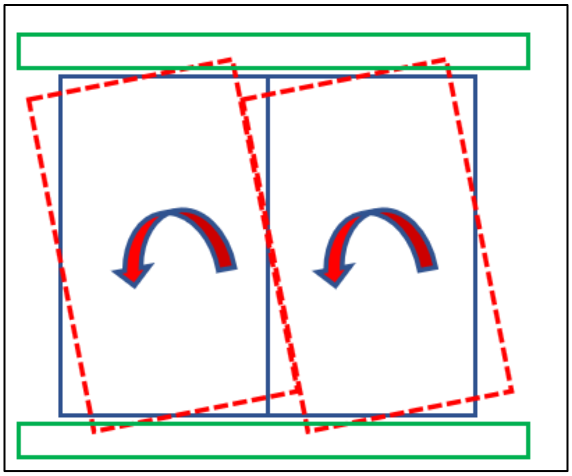


Figure 7: Front View; Desired rotation of sheathing in shear walls under test. Note the possible interference with the bottom beam and load beam (beams in green)

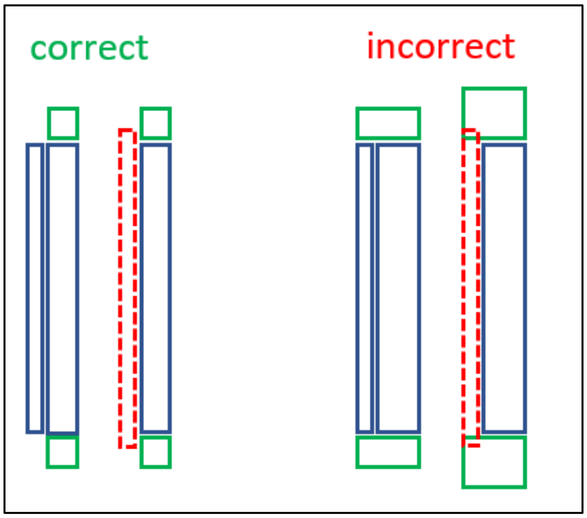
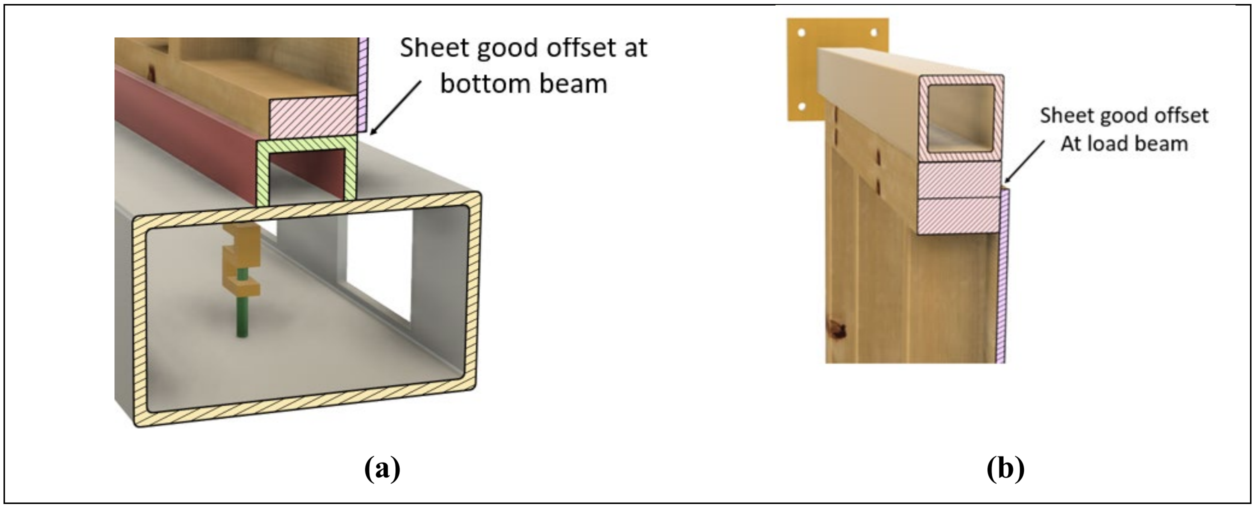


Figure 8: Side View; Correct rotation of sheathing without interference from the fixture (left two – before and during the test). Incorrect sample fixturing (right two – before and during the test)

Initially, both load and bottom beams featured flanges that interfered with the sheathing. This caused both the bottom and the load beams to buckle under the loads during testing. **Figure 9** is a cross-sectional view of the final design.



(a) **(b)**

Figure 9: Cross-sectional view of test apparatus with no interference between the sheathing and fixturing.: (a) bottom wood plate- to- sheathing, (b) top wood plates-to- sheathing

2.4 Rigid foundational tubular steel and load cells

In the literature review, the repeated theme of using steel tube sections to design foundation beams became apparent. Again, it became apparent that the shear wall testing apparatus utilize tubular steel sections as a foundational beam.

A 14" x 6" x 0.5" web mild steel tube section is a serviceable tool in the mounting of load cell sensors. It provides the necessary stiffness to span 7-ft while maintaining a strong floor mounting pattern with no buckling under the expected loads. The tube has a welded seam, so the weld should be on the bottom of the section. The countersink bolts hold down the tube to the bottom wall of the section (see **Figure 10**). The bolt heads are flush with the bottom, and the whole tube sits flush with the bottom wall. The ¾-16 flathead bolt goes up through the tube.

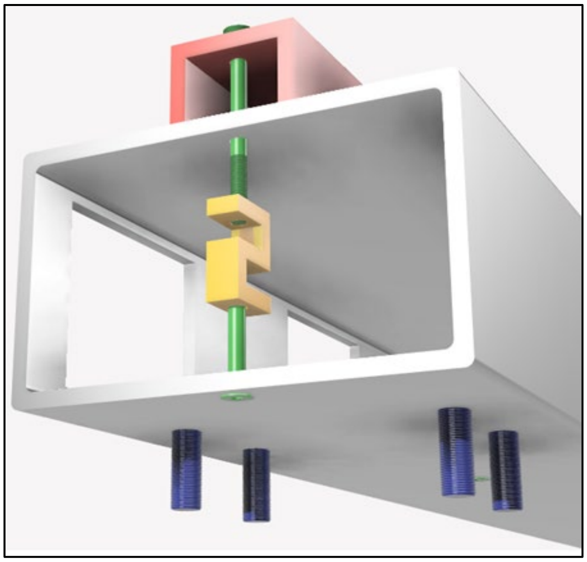


Figure 10: Foundational Tube and S type load cell as it attaches to the tube's lower wall

2.5 Sensors and calibration.

Altogether six bolts mount individual 10kip load cells (see **Figure 10**) that reside inside the tube cavity. S-type load cells selected have two threaded holes, one at each extremity, to capture loads in series with the mounting hardware. Once the load cells were mounted to the bottom of the tube, a corresponding clearance hole was blasted through the tube's top wall to access the top threaded hole in the load cell (see **Figure 11**). When tested, the shear wall test assembly is anchored to the load cells from the top wall. In the initial setup, the wall can be accurately fastened to the foundational tube using the tension 2500 lbs +/- 50 lbs. It takes several rounds of tightening before the values stop drifting. The use of load cells helps establish a reliable and consistent installation process. The data collected from the load cell during the test can help you understand the load transfer between the shear wall and its relative foundation. Variable cyclic tests can be tracked to a certain degree using these load cell data sets to have a broad understanding of shear wall dynamics. To measure uplift, optical sensors are mounted to the outside studs with lasers beamed towards the foundational tube to measure the uplift response. This technology is non-destructive as compared to a mechanical drop gauge, linear potentiometers (see **Figure 12**). The primary equipment used was a universal tensile testing machine. The equipment works as a transfer standard to calibrate our load cells. A force control method was implemented to compress and create tension on the load cells while building the data acquisition system—the load cells' data output from the MTS machine was used to create calibration curves.

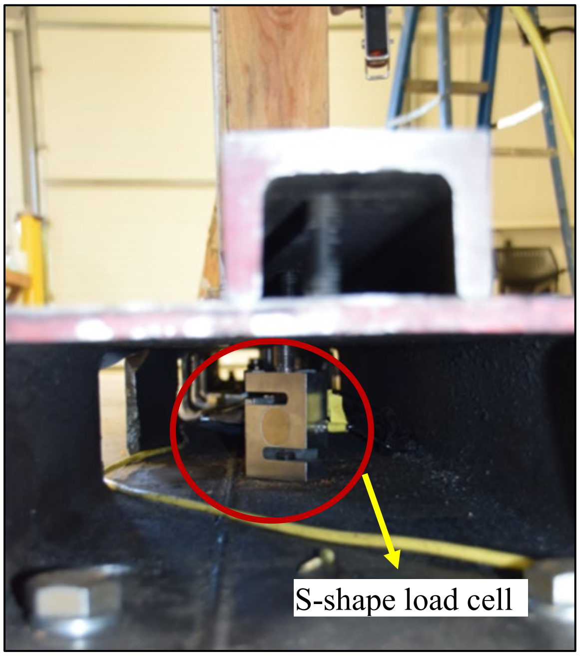


Figure 11:A look inside the tube. The wall section bolts onto the load cell. 6 loads cells provide the total anchorage for the test wall assembly to account for the total load transfer characteristics

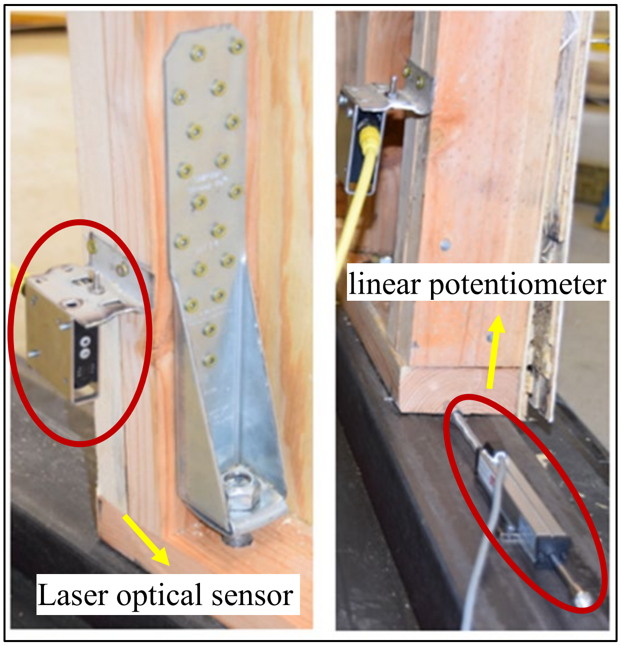


Figure 12: Optical Sensors mounted on terminal studs. Simpson Strong Tie and a 3/4 "anchor bolt (this bolt engages the load cell underneath the wall and inside the tube)

3 Test Specimen Construction

3.1 Utilizing Wall Jig Table

A professional carpenter was contracted to construct the shear walls to have squared test specimens more efficiently and accurately and demonstrate repeatable results.

An example of the differences brought to the table by a professional is using a sheet good enough to square the wall frame. With sheathing being perfectly square, the builder uses this component to square up the whole assembly. After taking notes on some fine aspects of wall assembly construction, a jig table was developed (see **Figure 13**) to expedite and standardize the construction process. The wall assembly jig controls each part of the assembly's location, such as studs and endplates. Special jig endplates were manufactured to control drilled holes' location; these endplates serve as drill bushings that aid in the drilling pilot holes in the studs' terminal ends, for example.

Figure 13: Shear Wall construction jig

Because the research is based on Douglas Fir, care must be taken when hand driving nails into this material so as not to bend the nails or overdrive the nails. It was also opted not to use a pneumatic framing nail gun and exclusively hand drive the nails to ensure accuracy.

Douglas Fir wood of Grade 2 or better was used for the test specimens because of its high strength and uniform properties compared with softwoods such as southern yellow pine [6]. Therefore, the use of Douglas Fir is critical as some of the structural adhesives can often surpass some common softwood species' strength, resulting in substrate failure. Specifically, the tensile strength can be greater in adhesives than in some softwood species.

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