

## **AC 2009-1596: TEACHING THE DESIGN: TIMBER SHEAR WALLS AND DEVELOPING STUDENT ENGINEERING JUDGMENT AND INTUITION THROUGH A HANDS-ON EXPERIENCE**

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# Teaching the Design: Timber Shear Walls and Developing Student Engineering Judgement and Intuition Through a Hands-on Experience

## Abstract

Engineering judgement and intuition are vital characteristic of the design profession. Engineering judgement and intuition are developed through experience. This experience is gained by designing a building (working with industry disciplines and the owner); analyzing the building (calculations); being part of the construction process (constructability), and walking through the final product (end user). Teaching design means, in part, developing engineering judgement and intuition. This may best be accomplished by incorporating active learning experiences.

For timber and masonry buildings, the shear wall is the lateral resisting system of choice. A hands-on experience has been developed as a simple exercise in constructing shear walls and then assessing the shear walls under a lateral load.

More specifically, in qualitative terms, the idea of wall rigidity is explored; actual construction experience is gained (for many students it is a first time experience in rough framing construction); the behavior and limitations of different wall sheathing is observed directly; insight is gained for code restrictions of different sheathing materials; and system behaviors such as overturning is directly observed.

As a strategy for developing students engineering judgment and intuition, this paper will give a detailed account of the hands-on shear wall exercise. Other educators are encouraged to implement, building upon, or transfer to other topics, the information contained within.

The students are upper level classmen in a timber and masonry design studio (9 hours per week of meeting time on a quarter system) of an architectural engineering program with an emphasis on structural engineering. The authors are licensed structural engineers with over 65 years of practicing experience, who have returned to academia.

The authors believe, from their direct background and experience, that it is important, for design, to begin giving the students non-traditional text book and calculation experiences. Giving the students a non-traditional experience, prior to graduation, is the emphasis of this paper.

## Introduction

Why is a shear wall called a shear wall? A shear wall is called a shear wall because the dominate deformation is shear. I have come to learn that this is a comment that is quick, easy, and obvious to make (obvious to the instructor) in lecture. To the student, the comment usually flies overhead and out-the-window: not good. Also having a tendency to go air borne and out-the-window are concepts of overturning, elastic deformation, and quality of construction. The sooner a student can grasp onto these concepts; the sooner engineering judgement and initiation can begin to grow. A hands-on approach may be a solution.

One area of application of judgement is in the building codes. Parameters maximums and minimum can vary from code to code. It takes understanding and judgement for an engineer to decode the differences in codes. For instance, in high seismic areas, why would some municipal codes prevent gypsum board as a shear wall sheathing, where others allow the use (at a greatly reduced capacity) compared to plywood?

### **The Hands-On Experience**

The hands on activity is simple, build four shear walls; attach the shear walls to a foundation; and hit the shear walls with a sledge hammer. With close supervision, this activity can be accomplished in a two hour period using four groups. Each group is responsible for one of the four shear walls.

The four shear walls differ with intent to demonstrate different behaviors. The four walls and their intent are list below.

1. A shear wall with no sheathing. A simple bare stud wall. This wall will demonstrate the necessity of sheathing and the idea of *racking*. When the wall is hit with the sledgehammer, the students experience how easy the wall moves (one hit). The wall by itself is not sufficient to resist lateral loading.
2. A shear wall with gypsum board sheathing. This wall will demonstrate the limitation of gypsum board. The limitation is the wall remains elastic for small lateral loading. The wall is typically hit with one or two really good swings of the hammer. At this point, the wall should be inspected. No visible permanent deformations are seen. However, with a couple more swings, permanent displacements are observed: screws digging into the gypsum board and change in vertical angle.
3. A shear wall with plywood sheathing: properly nailed. This wall demonstrates the ability for a plywood shear wall to resist large lateral loading. The students typically beat on the wall, only to get tired. There are no permanent deformations observed.
4. A shear wall with plywood sheathing: improperly nailed. This wall demonstrates that engineered systems are not “over designed”, but everything has its reason for being required. The bottom row of nailing is left out (don’t want to bend down to nail), and after one or two hits (on par with the wall with no sheathing), the wall pops up off the sill plate. The failure mechanism of overturning.

### **The Learning**

After the activity takes place, the students were noticeably more attentive to the discussion of shear walls and the code. I have drawn the conclusion the reason for this higher level of attention was that they were invested. They spoke with authority, for they had the direct experience. Such phrases as, “I disagree, did you not see how the gypsum formed little pile of dust. That means there was permanent change, not elastic behavior.” Or “He was sweating from hitting the wall so hard, and it still did not deform.” Or “Wind loading versus seismic, I guess it is the level of resistance, like a hurricane versus minimal winds.” From these discussions the instructor is given a great opportunity to explore further and the students are right there to follow.

How the walls relate to the code is talked about in general code terms. Those general terms are

- a minimal amount of sheathing is necessary in order to begin to resist lateral loading;
- the purpose of the code requirement (elastic behavior vs. one-time plastic);
- gypsum board can resist light lateral loading (minimum wind loads) in the elastic range, but for higher loading (seismic) it no longer remains elastic;
- plywood can resist a higher range of lateral loading elastically;
- make sure the wall is constructed as specified.

The assessment tool used to date is a simple “Top 10” list. Three or four weeks after the activity, without notice, I ask the students to take five minutes and write down the top ten things they remember from the shear wall activity. It is consistently the same each year. Below is an example of the student’s responses. The percentage indicates the number of participants with the same or similar response. There is no particular order to the numbering of the list. The number of students was 32 (16 each class over two years).

1. Quick and practical framing tips to help build a straight wall (100%)
  - a. Equal spacing of studs (30%)
  - b. Benefits of a framing hammer (25%)
  - c. Layout of anchor bolts location to sill plate (30%)
  - d. How to swing a hammer (35%)
  - e. It takes effort and work to frame, be in shape (20%)
  - f. How to pry a nail out of wood (10%)
2. Proper nailing of sheathing is very important (70%)
3. There is a large capacity for a properly constructed and nailed shear wall. (60%)
4. Sheetrock only has its capacity for one event – nail slip. (56%)
5. Related the building code to actual behavior (43%)
6. Load flow of double top plate (32%)
7. Racking action. (25%)
8. Everyone should do this experiment, even rough framers (12%)
9. Anchor bolts play an important role – uplift (12%)
10. Getting hit in the foot with a hammer hurts, wear proper foot ware (no Vans)

### **Additional Learning**

In addition to gaining insight on the capacity and behavior of a shear wall, the students gain direct experience in the basics of rough carpentry. It is always a benefit to know how something is constructed. The benefit allows an engineer to better detail a project for constructability. No matter how extensive the analysis of the project may be, if it cannot be built, it is of no use.

In a class there are usually a couple of students with framing experience. Try to team these students up with the students who have no experience, and there are always a couple of these inexperienced students. Also require that everyone swings a hammer. Verification that everyone is participating can be accomplished by listening; for the hammer sounds vary from “set-bang-bang-done” to “tap-tap-tap-tap-tap-bend-darn”.

## The Intuition

This hands-on activity occurs early in the course. Towards the second half of the course, the excitement and enthusiasm of the shear wall activity is forgotten. More traditional learning (lecture format) has been occurring, and more complex systems are introduced (built upon from the basic). It is during the discussion (calculations and analysis also) of the more complex systems, that a quick referral to the shear wall activity gives the student immediate insight and a reference point for understanding.

## The Activity

Prior to the activity, supplies are purchased, and tools are reserved. A handout is given showing what is to be built (See Appendix). Nothing more is said. The students are to organize themselves and begin building the wall. The instructor monitors the discussions and gives little helpful hints in the art of rough framing. If the instructor does not have experience in rough framing, then it is advised for the instructor to invite a framer to assist in the activity. It usually takes an hour and a half for the students organize, plan, and build the walls. This time does not include getting the students to the activity yard, making sure they have the proper safety equipment, or any other administrative task.

Below are pictures showing the construction and lateral loading of the walls (Fig. 1 – Fig. 9).



Fig. 1a: The Students Organize



Fig. 1b: The Students Organize



Fig. 2a: Laying Out the Wall



Fig. 2b: Laying Out the Wall



Fig. 3: Measuring for Anchor Bolts



Fig. 4a: Wall Framing



Fig. 4b: Wall Framing



Fig. 5: Double Top Plate Nailing



Fig. 6a: Applying Sheathing



Fig. 6: Applying Sheathing



Fig. 7: Taking a Break



Fig. 8: Bolting the Wall to the Foundation



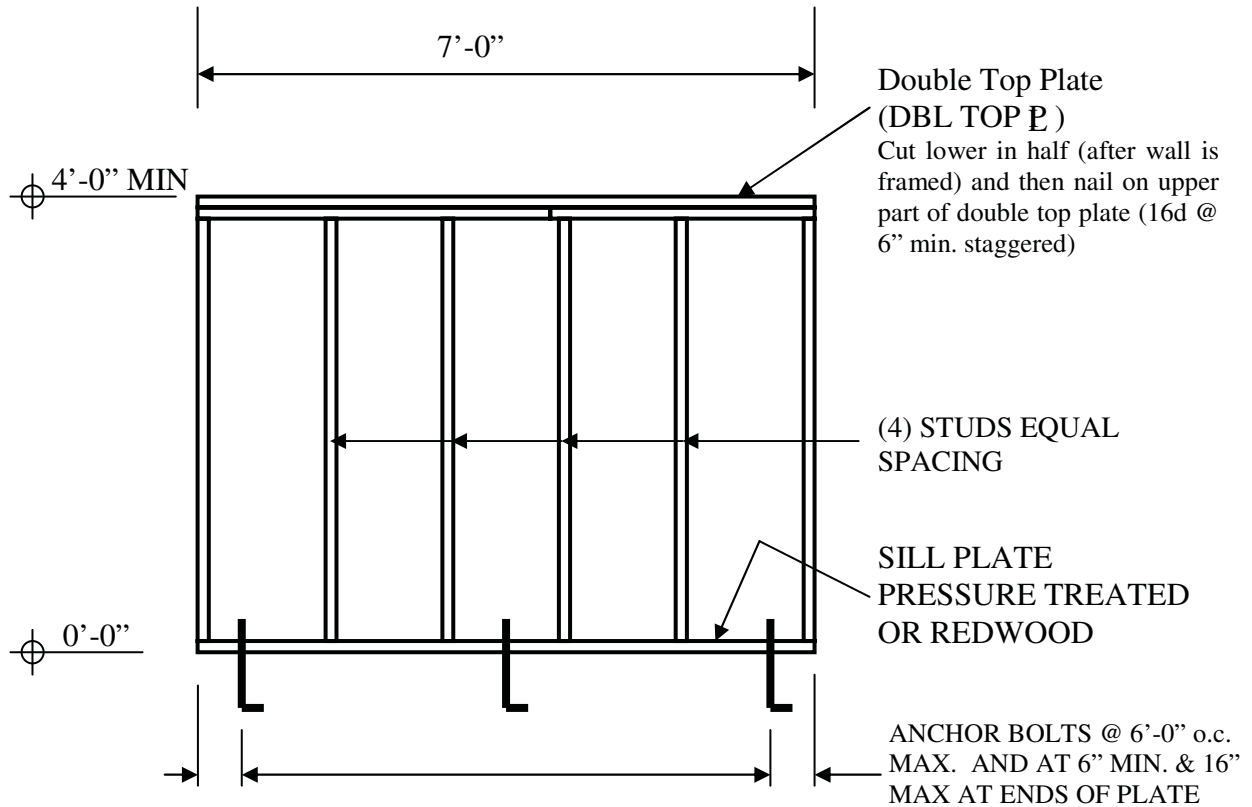
Fig. 9a: Lateral Loading



Fig. 9b: Lateral Loading

## Appendix

### Group 1: Wall 1 – No Sheathing



## WALL FRAMING

NTS

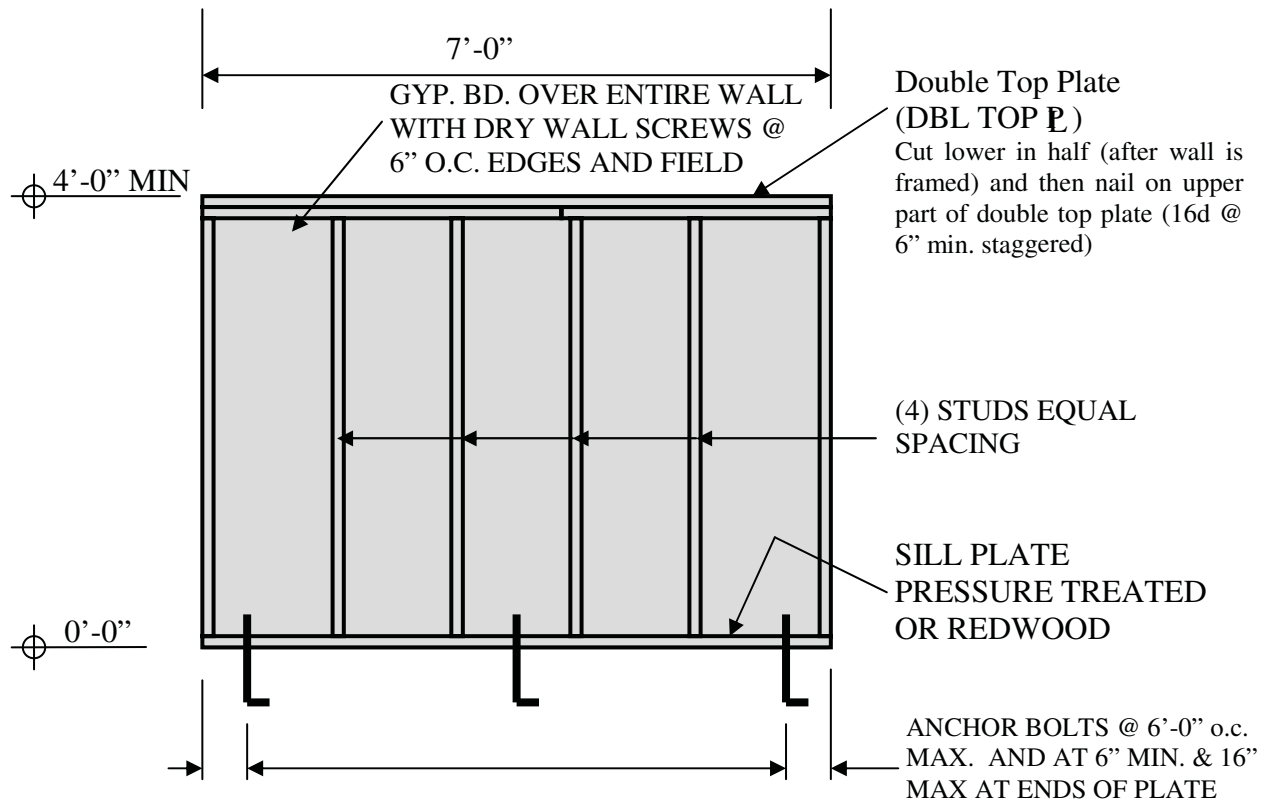
### GRADING

In order to qualify for any points, you must be in attendance during the entire time and participate.

10 pts for building, setting up, knocking down, taking off the foundation and clean up.



Group 2: Wall 2 – Gypsum Board Sheathed



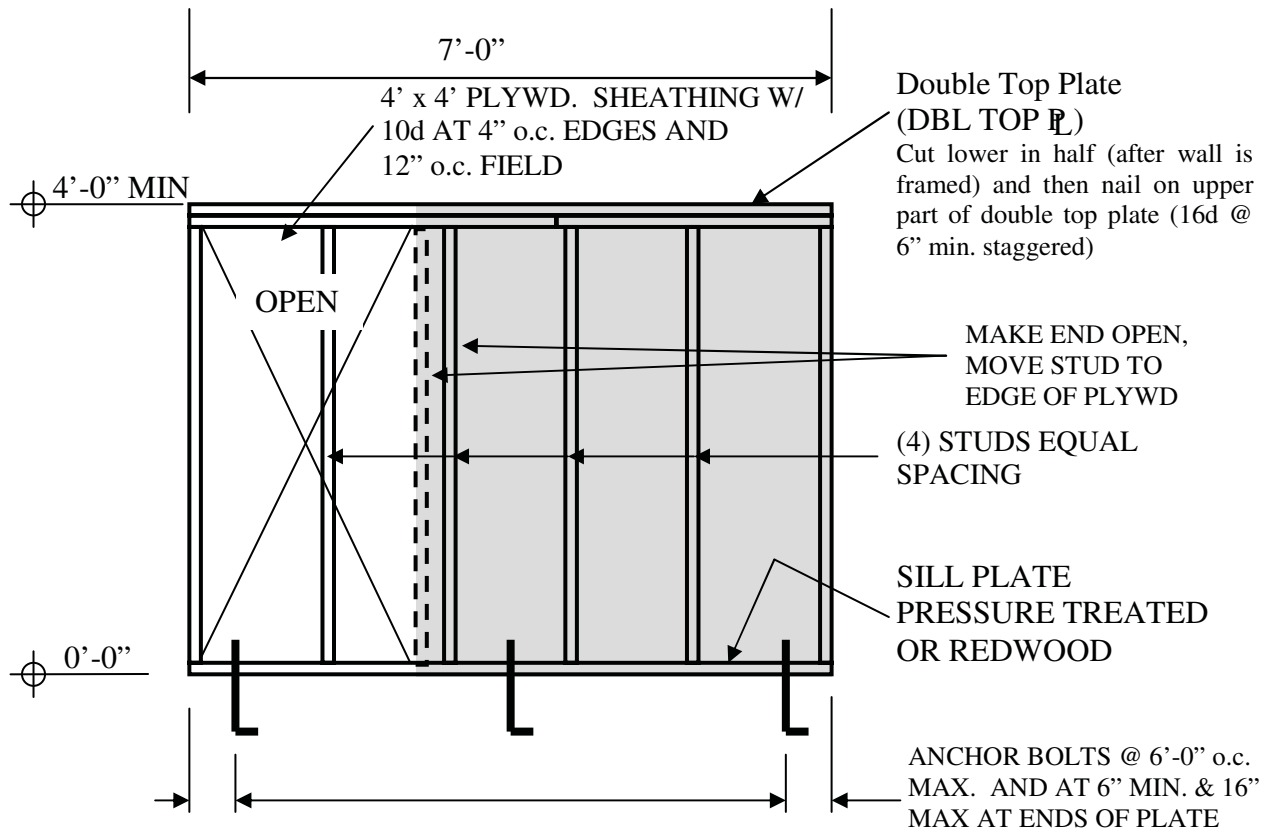
**WALL FRAMING ELEVATION**  
NTS

GRADING

In order to qualify for any points, you must be in attendance during the entire time, and you must participate.

10 pts for building, setting up, knocking down, taking off the foundation and clean up.

Group 3: Wall 3 – Plywood Sheathed and Properly Nailed



WALL FRAMING ELEVATION

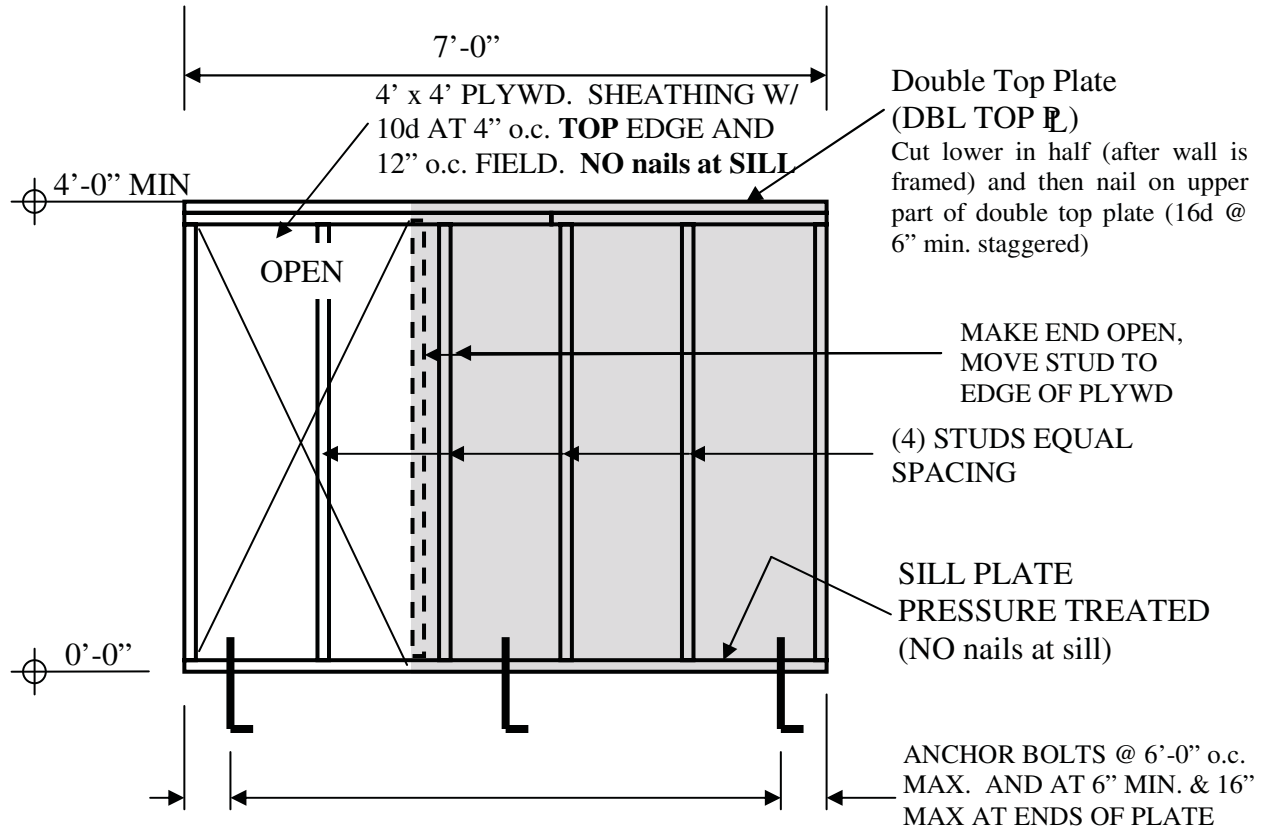
NTS

GRADING

In order to qualify for any points, you must be in attendance during the entire time and participate.

10 pts for building, setting up, knocking down, taking off the foundation and clean up.

Group 4: Plywood Sheathed and Improperly Nailed



WALL FRAMING ELEVATION  
NTS

GRADING

In order to qualify for any points, you must be in attendance during the entire time and participate.

10 pts for building, setting up, knocking down, taking off the foundation and clean up.