Diaphragms and Shear Walls

Load Paths

Vertical Loads
- gravity
- D, L, Lr, S,

Lateral Loads
- wind
- seismic
Lateral Force Resistance

Stability requires at least 2 points of intersection.

Force is more evenly resisted with centroid of walls in the kern of slab.
Definitions

Diaphragm – a flat structure which acts as a deep beam to resist in plane loads.

Shear Wall – a vertical structure which acts as a cantilevered diaphragm

Chord – the edge member of a diaphragm

Blocked Diaphragm – all panel edges are supported by (and nailed to) framing member

Unblocked Diaphragm – only the short, 4 ft edge is supported by framing member. This is the most common situation.

Drag Strut – at the edge of the diaphragm it distributed the shear force from one diaphragm to another – e.g. from floor diaphragm to shear wall
Diaphragm Types

Blocked
- all edges supported and nailed
- stronger
- more expensive

Unblocked
- more common type
- lower capacity
- less stiff

Diaphragm Selection
For Shear Force
roof and floor diaphragms
Example 1:
residential roof diaphragm
trussed roof (2x lumber)
unblocked
capacity 180 plf - any direction
Diaphragm Selection
For Shear Force
roof and floor diaphragms

Example 2: commercial roof diaphragm trussed roof (2x lumber)
capacity 350 plf - Case 1

Three Shear Wall Types

Design considerations:
- Sheathing – type and thickness
- Sheathing nailing – size and spacing
- Chord design – tension and compression
- Collector design – tension and comp.
- Anchorage – hold-downs, shear ties
- Shear panel proportions – h:w
- Deflection
**Shear Wall Types – 1. Segmented**

Acts like a vertical cantilever beam

**Let-in Wall Bracing – 45°** - limited to single or top story

**Wall Board** – requires 8 ft length

**Wood Structural Panel** – requires 4 ft length – 3 times stronger by length

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**Shear Wall Types – 2. Force transfer around openings**

The full wall acts as a unit.
Requires rational analysis

Only 2 end hold-down ties are generally needed.

The wall elements need to be tied across tension zones - around openings

Heavier sheathing and nailing is generally required.

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*Source: Peter von Buelow, University of Michigan, TCAUP*
Shear Wall Types – 3. Perforated shearwall

- Semi-empirical method based on testing.
- Similar to the force transfer method, but with simplified details.
- Generally lower capacity and lower stiffness.
- Follows IBC 2305.3 – see limitations of use.
- Capacity of the “weak direction” (lacking tension tie-down) is reduce by $C_o$ factor.

![Diagram of weak and strong direction in shearwall]

Shear Wall Connections

Connections need to transmit force in 6 directions (3 axes)

- Toenails – not adequate
- Hold–down Anchors
- Base Shear Anchors

![Diagram showing engineered shear walls with specific nail size and spacing requirements]
Shear Wall Design Elements

- Panel Thickness
- Panel Grade
- Nail spacing
- Base shear anchors
- Hold down anchors (at ends of each wall)
- Placement for lateral stability
- Fastening at edges (chords)

A Shear Wall...  A Diaphragm...

<table>
<thead>
<tr>
<th>Is vertical</th>
<th>Is horizontal (or nearly so)</th>
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<tbody>
<tr>
<td>Is designed like a cantilevered beam</td>
<td>Is designed as a simply supported beam</td>
</tr>
<tr>
<td>Table has only blocked values, because a shear wall is always blocked*</td>
<td>Table has both blocked and unblocked diaphragm values</td>
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</table>

* A code requirement.

Drag Struts

Double Top Plate

FIGURE 11
SHEAR WALL SEGMENT
Local building codes typically stipulate a minimum $w$ of $h/3.5$

FIGURE 12
BASE SHEAR

FIGURE 13
OVERTURNING

FIGURE 14
TOP PLATE DRAG STRUTS

Double top plate acts like a drag strut in these locations (over openings).
Shear Wall Selection Table

special case diaphragm

Example:
Commercial building shear wall
w/ 5/8" gypsum on outside
for 1 hr. fire rating.
required capacity = 437 plf

<table>
<thead>
<tr>
<th>Panel Grade</th>
<th>Minimum Nominal Panel Thickness (in.)</th>
<th>Minimum Nail Penetration in Framing (in.)</th>
<th>Panels Applied Direct to Framing</th>
<th>Panels Applied Over 1/2&quot; or 5/8&quot; Gypsum Sheathing</th>
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<td>6d</td>
<td>200</td>
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<td>1-3/8</td>
<td>8d</td>
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<td>APA Structural Grades</td>
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<td>1-1/2</td>
<td>10d</td>
<td>340</td>
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<tr>
<td>APA Structural Grades</td>
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<td>6d</td>
<td>180</td>
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<td>1-3/8</td>
<td>8d</td>
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<td>19/32</td>
<td>1-1/2</td>
<td>10d</td>
<td>340</td>
</tr>
</tbody>
</table>

(a) For framing of other species (1) Find specific gravity for species of lumber in the APA National Design Specification. (2) For common or galvanized box nails, find shear value from table above for nail size for actual grade. (3) Multiply value by the following adjustment factors: Specific Gravity Adjustment Factor = 1.00 – 0.05 SG, where SG = specific gravity of the framing. This adjustment shall not be greater than 2.5. (4) All panel edges backed with 2-inch nominal or wider framing. Install panels either horizontally or vertically. Space nails maximum 8 inches o.c. along intermediate framing members for 3/8-inch and 7/16-inch panels installed on studs spaced 24 inches o.c. For other conditions and panel thicknesses, space nails maximum 12 inches o.c. on intermediate supports. (5) 3/8-inch or APA RATED SIDING 16 sc is minimum recommended when applied direct to framing as exterior siding.

(d) Shears may be increased to values shown for 15/32-inch sheathing with some nailing provided (1) studs are spaced a maximum of 16 inches o.c., or (2) if panels are applied with long dimension across studs. (e) Framing at adjoining panel edges shall be 3-inch nominal or wider, and nails shall be staggered where one run exceeds 5 inches o.c. (f) Framing at adjoining panel edges shall be 3-inch nominal or wider, and nails shall be staggered where 10 nails forming panel framing into framing of more than 1.5 inches are spaced 3 inches o.c.

(g) Values apply to all common plywood APA RATED SIDING panels only. Other APA RATED SIDING panels may also qualify on a proprietary basis. APA RATED SIDING 16 sc plywood may be 11/32-inch, 3/8-inch or thicker. Thickness at point of nailing on panel edges governs shear values.

Typical Layout for Shear Walls

- **APA Rated Sheathing or APA Rated Siding 303**
- **1/4" steel bracket (A Hail-down)**
- **Bolts to framing, size as required**
- **Sill plate, Bolt to foundation**
- **Concrete foundation**

Pressure-treated barrier may be required.

**SEGMENTED SHEAR WALL**

SILL BOLTS OR NAILS
TIE-DOWN ANCHOR

Peter von Buelow
University of Michigan, TCAUP
Diaphragm and Shear Wall Example

Given: Wood frame structure shown
Lateral wind load = 30 psf
2x rafters and studs

Find: Design roof diaphragm sheathing and shear walls on short side.
Use APA sheathing tables in X305

Roof Diaphragm

calculate forces as in a deep beam.
Roof Diaphragm Panel

Choose Panel from APA chart

Try first the lesser quality:
- unblocked
- APA rated sheathing
- 2" rafters
- edge shear force = 257 plf

Try:
unblocked, case 1, 19/32"
10d nails at 6" edge 12" inter. o.c.
or
blocked, any case, 15/32"
8d nails at 6" edge 12" inter. o.c.

Roof Diaphragm Chord

For the diaphragm, the chords carry the moment couple and the panels carry the web shear

Tension generally controls.

Chords are usually the double top plates of the walls, but for simple but jointed members only 1 member is acting at the joint. Therefore Area is for 1 2x4
Shear Wall

Check shear wall width:
by IBC 2305.3.4:
for Wind: \[ w = \frac{h}{3.5} \]
for Seismic: \[ w = \frac{h}{2.0} \]

\[ w = \frac{16'}{3.5} = 4.57' < 6' \text{ ok} \]

Calculate the shear carried in plf by walls
Total force / sum of width = PLF

the PLF x wall width = force on wall

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Shear Wall Panel

Choose panel from APA shear wall chart
for 360 plf

Try APA rated sheathing
15/32" 8d at 4" o.c.
380 > 360 plf \text{ ok}

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(b) All panel edges backed with 2-inch nominal or wider framing. Install panels either horizontally or vertically. Space nails maximum 6 inches o.c. along intermediate framing members for 3/8-inch and 7/16-inch panels installed on studs spaced 24 inches o.c. For other conditions and panel thicknesses, space nails maximum 12 inches o.c. on intermediate supports.

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Typical Layout for Shear Walls

[Diagram of shear wall boundary, blocking, and foundation resistance]
Shear Panel Top Cord

Find the greatest net tension force:
1. Find the net PLF force in the top chord by taking the difference between the force applied by the diaphragm and the resisting force of the shear wall.
2. Convert the PLF force to total force on the wall segment by multiplying PLF x w.
3. Graph the change in force along the chord starting at one end. The free ends should both be zero.
4. Choose the highest tensile force and find the actual stress in one member (2x4).
5. Check against the factored allowable for the wood species and grade.

\[
\begin{align*}
\text{Max Tension Force} &= 617 \text{ kips} \\
T &= \frac{617}{5.25} = 118 \text{ psi} \\
\text{Plf} &= 1080 > 118 \text{ kips (as above for 5 ft. h) }
\end{align*}
\]

Shear Wall Base Anchors

Find the force in each fastener and select them from manufacturer’s literature.

For 8’ shear wall:
\[
R = 2880 \text{ kips}
\]
\[
M = Rh = 2880(16) = 46080 \text{ in-kips}
\]
\[
T = \frac{M}{b} = \frac{46080}{8} = 5760 \text{ kips}
\]

Design the down C 6k.

Base Shear:

For studs @ 24” OC.
4 spaces - say 4 bolts
\[
R/n = \frac{2880}{4} = 720 \text{ lb/bolt}
\]
Shear Wall End Holdown Anchor

Shear Wall – base plate anchor
for A307 bolts Fy = 36 ksi
root area for 3/8” bolt = 0.0742 in²
shear capacity = 36000 x 0.0742 = 2671 lbs.

Steel L Hook Anchor Bolts

Multiple product options available

Brands
CALSDEWEL, FABORY and GRAINGER APPROVED

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<tr>
<th>Anchor Dia.</th>
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