Deflection of Light Frame Wood Diaphragms

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Abstract

This paper takes an in-depth, parametric look at the deflection of wood diaphragms to better understand the diaphragm deflection equation and how it is utilized. This work is intended to assist engineering judgment when calculating mid-span diaphragm deflections in wood structures. The deflection equation is explained for each component (bending, shear, and chord slip) to show how each contributing term should be addressed. The diaphragm deflection equation was taken from the 2008 edition of the Special Design Provisions for Wind and Seismic (American Forest & Paper Association). Background information about each term was gathered from multiple sources and conglomerated into this paper. The bending term included a parametric study using virtual work, while discussion of the other two terms focused on deciphering information already available.

Introduction

Diaphragm deflection can often have a significant impact on design. For example, a brittle façade or veneer such as brick cannot withstand the same out-of-plane deflections as wood. Furthermore, expensive modifications to wood structures, or even having to use a completely different structural material because of excessive deflections, are two situations designers wish to avoid. Lastly, seismic story drift requirements in section 12.12.1 of the ASCE/SEI 7-05 (American Society of Civil Engineers [ASCE], 2005) must be met, so it is important that the diaphragm deflection is calculated accurately.

Currently, the 2008 edition of the Special Design Provisions for Wind and Seismic (SDPWS) gives the diaphragm deflection equation in 3 terms: bending, shear, and chord slip. The derivation and wording of the terms and variables are not explained in a clear, easily understood manner, and thus, designers may come to a predicament. A design professional must perform a multitude of design checks and typically does not have time to research the background of the diaphragm deflection equation and embedded assumptions. Consequently, a comprehensive explanation, reinforced with an example, would benefit practicing engineers by helping them gain a better fundamental understanding of the calculation methodology, assumptions and sources of data.

Objectives

The primary objective of this paper is to provide practical information regarding light frame wood diaphragm deflection to design professionals. The analysis and discussion of each term of the deflection equation is presented by citing previous literature and research. The bending term of the deflection equation also includes results and interpretation of a parametric study completed for this investigation. An example is included to reinforce the recommendations and comments discussed throughout the paper.

Methodology to Calculate Diaphragm Deflection

Diaphragms are a component of wood-framed buildings that resist and transfer lateral forces produced by wind or earthquakes. Accurate calculation of diaphragm deflection is important to engineers because excessive deflection may cause serviceability issues or overall failure of the structure. Originally, the diaphragm deflection equation was made up of four terms, but has now been converted to three terms. The *Shear term* section below delves further into the reasons behind the change from four terms to three.

The three-term equation for the deflection of a diaphragm under distributed horizontal loading (wind or seismic) can be calculated using the following equation (American Forest & Paper Association [AF&PA], 2008):

$$\delta_{dia} = \overset{(bending)}{\frac{5vL^3}{8EAW}} + \overset{(shear)}{\frac{0.25vL}{1000G_a}} + \overset{(chord\ slip)}{\frac{\sum x(\Delta_c)}{2W}} \tag{1}$$

where:

v = induced unit shear (lb/ft)
L = diaphragm dimension perpendicular to the direction of applied force (ft)
E = modulus of elasticity of diaphragm chords (psi)
A = area of chord cross-section (in^2)
W = width of diaphragm in direction of applied force (ft)
G_a = apparent diaphragm shear stiffness (kips/in)
x = distance from chord splice to nearest support (ft)
Δ_c = diaphragm chord splice slip at the induced unit shear (in)

Bending term:

The first term in Equation 1 is derived from the deflection equation of a simply-supported beam under a uniformly distributed load, but rearranged to be more easily utilized for unit shear values that are commonly calculated for diaphragms. Each variable in the equation is straightforward with the exception of “A”. When looking at the equation, engineers must make a judgment about what cross-sectional area to use for the chord. In diaphragms, the top plate of the wall is considered the diaphragm chord, but for typical top plate construction that has two pieces of dimension lumber stacked on top of one another, is the area taken for the equation that of one or two pieces of lumber? By deriving the equation below, the answer to this question becomes clearer.

First, define the mid-span deflection of a simply-supported beam with a uniformly distributed load, the maximum shear at support of this simply supported beam, the unit shear, and the moment of inertia equation that applies to the chord members of wood diaphragms (parallel axis theorem):

$$\delta_{beam} = \frac{5wL^4}{384EI} \tag{2}$$

$$V_{\max} = \frac{wL}{2} \qquad [3]$$

$$v = \frac{V_{\max}}{W} \qquad [4]$$

$$I = \frac{bh^3}{12} + Ad^2 \qquad [5]$$

where:

w = distributed load on beam (lb/ft)
I = moment of inertia of resisting chords (in^4)
V_{max} = maximum shear at beam end support (lb)
d = distance between centroids of diaphragm and chord (in)
b = thickness of chord (in)
h = width of chord (in)
A = area of chord cross section (in^2)

The diaphragm is treated like a deep beam with the sheathing acting as the web, and the two chords acting as flanges. In wood diaphragms, the contribution of sheathing to the moment of inertia is conservatively neglected, and thus Equation 5 only accounts for the chord members. The moment of inertia of the chords about their own axes is also conservatively ignored, which eliminates the first term in Equation 5. The distance, "d", to the chord can then be replaced by one-half of the diaphragm width (W/2) and the whole term multiplied by two since there are two chords being considered, one tension and one compression, resulting in Equation 6. Note that half of the diaphragm width is an approximation for the value of "d" because the actual distance of "d" to the centroid of the chord does not go out to the edge of the wall. Figure 1 shows the layout of a typical floor diaphragm, with the shaded members being the contributing chords in the calculation.

$$I = \frac{AW^2}{2} \qquad [6]$$

Next we substitute Equations 3 and 6 into Equation 2:

$$\delta = \frac{5\left(\frac{2V_{\max}}{L}\right)L^4}{384E\left(\frac{AW^2}{2}\right)} = \frac{5\left(\frac{2V_{\max}}{W}\right)2L^3}{384EAW} \qquad [7]$$

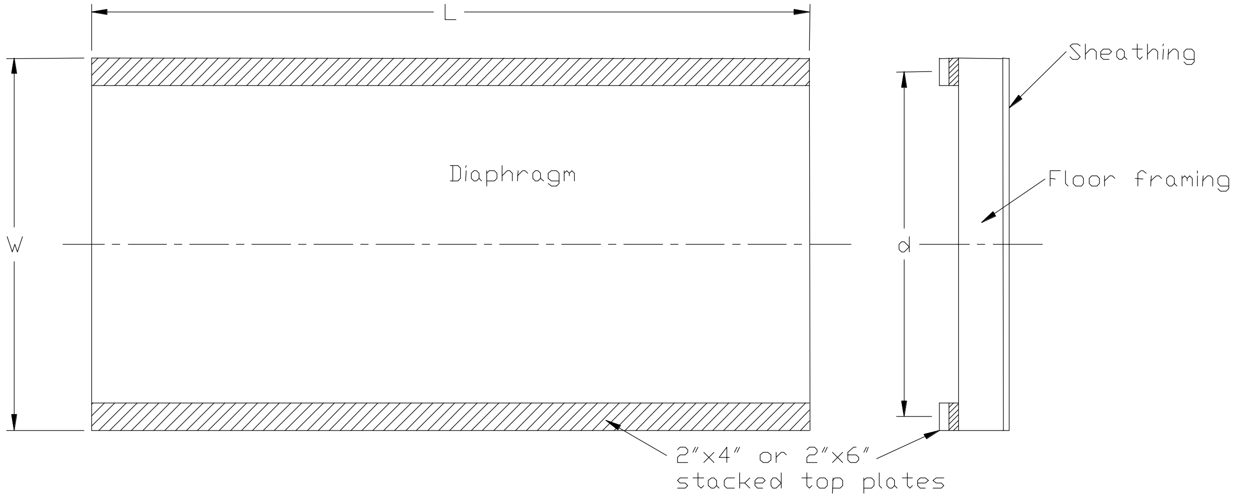


Figure 1 - Diaphragm layout

Inserting Equation 4, replacing V_{max}/W with v:

$$\delta = \frac{5(4)vL^3}{384EAW} \qquad [8]$$

Converting length units to inches for v, L, and W:

$$\delta = \frac{5(4)v\left(\frac{1ft}{12in}\right)L^3\left(\frac{12in}{1ft}\right)^3}{384EAW\left(\frac{12in}{1ft}\right)} = \frac{5(48)vL^3}{384EAW} = \frac{5vL^3}{8EAW} \qquad [9]$$

Recall that the *A* term used in the parallel axis theorem for moment of inertia was the area of one top plate on one side of the diaphragm, then the equation was doubled to account for the other side of the diaphragm. For a nailed, double top plate, should the designer use the cross sectional area of one piece of lumber or two when calculating the deflection from bending? If full composite action of the double top plate members is assumed, the *A* value in the deflection equation would be the area of both pieces of lumber comprising the chord. Full composite action is difficult to achieve with mechanically fastened assemblies because slip must occur before mechanical fasteners (e.g. nails) begin to take load. If no composite action was assumed, the area of one piece of lumber would be used. The *A* term of the deflection equation is discussed in greater depth, with results of a parametric study, in the *Procedure for Virtual Work* section

Shear term:

The original diaphragm deflection equation, given in the Commentary of SDPWS (AF&PA, 2008), consisted of four terms:

$$\delta_{dia} = \overset{\textit{(bending)}}{\frac{5vL^3}{8EAW}} + \overset{\textit{(panel shear)}}{\frac{vL}{4G_v t_v}} + \overset{\textit{(nail slip)}}{0.188Le_n} + \overset{\textit{(chord slip)}}{\frac{\sum x(\Delta_c)}{2W}} \qquad [10]$$

The derivation of the two shear terms (panel shear and nail slip) can be found in the ATC-7 Guidelines for the Design of Horizontal Wood Diaphragms (Applied Technology Council, 1981) and in internal APA documents on diaphragm and shearwall deflection (APA, 1974-1977). The panel shear and nail slip are assumed to be inter-related and therefore they have been combined into a single shear term as shown in Equation 1. The nail slip, given by the term e_n refers to nails used to attach the wood panels to the framing. The combined shear term includes the variable G_a, which represents apparent diaphragm shear stiffness. The SDPWS gives G_a values based on sheathing grade, nail size, fastener penetration, panel thickness, and minimum nominal width of framing, which are based on limited testing (APA – The Engineered Wood Association, 1952, 1954, and 1966). Values for G_a can be found in SDPWS 2008 Tables 4.2A through 4.2D. Note that when selecting a G_a value from one of the SDPWS tables, there are four footnotes that should be addressed which may lead to a reduced value.

The four-term equation for diaphragm deflection can be used in lieu of the three-term equation if desired. However, the table look up from the tables mentioned above for the G_a term is relatively quick and easy. The two diaphragm deflection equations are equivalent at the critical strength design level, which is $1.4v_S$. Figure C4.3.2 in the 2005 SDPWS graphs how the 4-term and 3-term equations compare, with the maximum difference between the two equal to 0.045 inches. When the unit shear is below $1.4v_S$, the 3-term equation becomes more conservative. Although the differences between the two are small, it is recommended to consistently use the same equation for diaphragm design because the small differences can influence load distribution assumptions based on relative stiffness (AF&PA, 2008).

The shear term tends to contribute the largest amount to the overall diaphragm deflection, especially if the diaphragm is unblocked. If a diaphragm is unblocked, the G_a term should be multiplied by a 0.6 or 0.4 factor depending on the framing and sheathing layout (AF&PA, 2008). For a case 1 layout, the coefficient is 0.6, and for all others the coefficient drops to 0.4. See the *Overall deflection* explanation below for further information regarding unblocked diaphragms.

Other modification factors in the shear deflection term relate to green lumber framing (moisture content greater than 19%), plywood sheathing instead of Oriented Strand Board (OSB), and any framing lumber species other than Douglas Fir-Larch (DF-L) or Southern Pine. These factors are discussed in the 2008 SDPWS footnotes of Tables 4.2A, 4.2B, 4.2C, and 4.2D (AF&PA, 2008).

Chord slip term:

The last term in the diaphragm deflection equation takes into account chord slip. The derivation of this term can be found in the ATC-7 Guidelines for the Design of Horizontal Wood Diaphragms (Applied Technology Council, 1981) and in an internal APA document on diaphragm and shearwall deflection (APA, 1974-1977). One of the variables in this last term, $\Delta_{c,}$ is not very well documented or explained in the wood design literature. Hoyle & Woeste (1989) assume a Δ_c value of 1/16-in. (0.0625 in.) in an example problem, but merely state that the splices are designed such that there "might" be 1/16-in. slip in each splice. These authors also insinuate from the calculations that the $\Sigma\Delta_c x$ for one chord may be doubled to account for the other chord. Their example problem was a warehouse with 2x8 bolted chords – not a common structure in current design.

In an example problem given in Breyer et. al. (2007), the authors assumed that the Δ_c variable is 1/32-in., which is half of the 1/16-in. allowable oversize for bolt holes in that design example. As mentioned before, typical modern diaphragm construction would not utilize 2x8 stud walls and top plates, and often will not include bolts. Breyer et. al. (2007) also note that the calculated value for $\Sigma\Delta_c x$ for one chord can be doubled for the other chord.

In contrast, APA research shows that compression chord slip is about 1/6 of the tension chord slip on average. Furthermore, slip for tension chords ranged from 0.011 to 0.156 in., with an estimated average of 0.03 in. As a result, the *Diaphragms and Shearwalls, Design/Construction Guide* (APA – The Engineered Wood Association, 2007) assumed a tension chord slip of 0.03 in. and a compression chord slip of 0.005 in. in their example.

The 2008 SDPWS gives the following equation for Δ_c:

$$\Delta_c = \frac{2(T\,or\,C)}{\gamma n} \qquad [11]$$

where:

T = tension chord force (lb)
C = compression chord force (lb)
γ = load-slip modulus for dowel-type fasteners (lb/in/nail) [See *National Design Specification for Wood Construction* (NDS) Section 10.3.6 (AF&PA, 2005)]
n = number of nails or bolts

Since the chord forces of the diaphragm are equal, it is also taken that the slip in each chord will be the same. The reasoning behind this is the assumption that the butt joints in the compression chord might have a gap that exceeds the splice slip, and thus the implementation of either chord force in the equation, and then doubling it to account for slip on each side of the joint. APA research concluded that compression chord slip was 1/6 of the tension chord slip, most likely indicating that the butt joints had little to no gap.

It should be noted that the γ term was developed from tests of bolts, not nails (Wilkinson, 1980). Although this term was originally used only for bolts and lag screws (AF&PA, 1997), it has since been adapted for all dowel-type fasteners. In the load-slip modulus equation, the diameter, D, is still described as the diameter of a *bolt* or *lag screw* in the 2005 NDS, yet the equation is utilized for nails in the diaphragm deflection calculation of the 2008 SDPWS Commentary (AF&PA, 2008). How appropriate this equation fits for nails is unknown at this point until further research is completed to create load-slip curves and calculate a load-slip modulus for a variety of nails.

Some research (McCutcheon 1985, Ehlbeck 1979, and Falk et. al. 1989) offers some theories and background information regarding nail-slip and nailed connections. However, none of the tests evaluated a number of different nail types or diameters. Engineers should be aware of where this load-slip modulus was derived, and that bolt slip and nail slip are not equal, as bolted connections generally have higher stiffness than nailed connections due to the larger fastener diameters.

Overall deflection:

Research by the APA shows that unblocked diaphragms deflect about 2.5 times that of blocked diaphragms. The SDPWS took this into consideration for the shear term, as mentioned earlier; however, nothing was brought up about any modifier to the total overall calculated deflection.

Again, engineering judgment is left to fill in the gaps. Although APA research gives the recommendation of multiplying the *overall* calculated deflection by 2.5 or 3, depending on the framing spacing (Form No. L350A, 2007), the SDPWS fails to address the issue, but does in fact mention the APA research. Thus it seems appropriate to modify the G_a term when necessary, but not increase the total calculated deflection in addition to that. The deflection from the shear term would increase by a factor of 2.5 in most cases (dividing by $0.4G_a$), which ultimately leads to a heavy impact on the total deflection already since the shear term is often the biggest contributor to overall deflection.

Results in Appendix B show that the shear term often contributes the largest percentage to the overall deflection. As the aspect ratio increases, the shear term becomes less dominant, and in some cases can be smaller than the other two terms. This most likely will occur when the G_a value is fairly high (e.g. OSB sheathing instead of plywood), and when the lumber length of the chord is relatively small (e.g. 8 ft) resulting in many chord splices. The minimum, maximum, and average contributions of each deflection term are summarized in Appendix B for diaphragm widths of 20 to 40 feet and lengths of 40 to 80 feet.

Virtual Work Analysis of Bending Term

To further delve into the issue of the appropriate chord area, A, of the bending term, a parametric study was undertaken to help determine if it is reasonable to assume full composite action of the double top plates, and thus, all four elements (two stacked 2x4 or 2x6 members on each side of the diaphragm) contributing to resist diaphragm deflections. The study focused on diaphragm widths of 20 to 40 feet and diaphragm lengths of 40 to 80 feet, with 4-ft increments for both the length and width. Top plate splice locations were assumed to be worst case scenario of every four feet (i.e. 8-ft lumber pieces), with splices lining up with one another on opposite sides of the diaphragm. Calculated bending deflections for each diaphragm size were based on both nominal 2x4 and 2x6 top plate chord members.

For all portions of the chord where the two stacked top plates are between splices, the contributing area to the moment of inertia is considered to be the full cross-section, or both plies for each chord. These segments are from the first nail on either side of the splice to the last nail before the next splice. All portions of the chord at a splice, from the last nail on either side of the splice, assumed a cross-sectional area of one ply per chord. Note that it is not just a gap distance between spliced members, but a distance between two nails on either side of the splice because any part of the member beyond the last nail does contribute to bending stiffness.

Three different end nail distances at chord splice locations were considered (see Figure 2): a maximum of 6 inches, a middle value of 4 inches, and a minimum value of 15 times the diameter of the nails being used. It was assumed that 16d box nails were used (diameter of 0.135 inches), and thus the minimum end nail distance was 2.025 inches. These end nail distances occur at each side of the splice, resulting in the total distance being twice that of the values mentioned above.

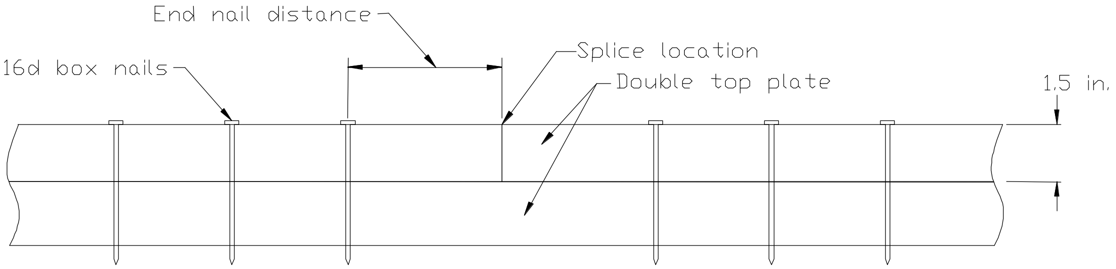


Figure 2 - End nail distance in diaphragm chords

The method of virtual work was used to determine the bending deflection using a varying moment of inertia value along the chords. The equation for the mid-span deflection of a beam with varying moment of inertia and under a uniformly distributed load was derived using virtual work (see Appendix). Overall calculated deflection values were given in terms of w/E and then compared to Equation 2. These values for each of the end nail distances were then compared to the case assuming just a one-ply tension chord and a one-ply compression chord contributed to the moment of inertia. Examples of calculated values are discussed below, and summarized in Table 1.

Results of Parametric Study:

The results in Table 1 show the calculated diaphragm deflections (bending component) for the varying assumptions of end nail distance. The deflections were normalized to the deflection predicted from assuming only one ply for each chord (most conservative assumption). For the case of 6 in. end nail distance, the calculated bending deflection was roughly 63% of the deflection of a one-ply chord. When the minimum end nail spacing of 2.025 in. was used, the bending deflection dropped to 54% of the deflection of a one-ply chord. These values make sense, considering a result of 50% would basically mean a continuous two-ply chord member on each side of the diaphragm.

A parametric analysis was conducted to understand the influence of diaphragm aspect ratio on the chord area assumption. As expected, the bending components of deflection were relatively insensitive to aspect ratio. However, the contribution of bending to the entire diaphragm deflection would be expected to vary.

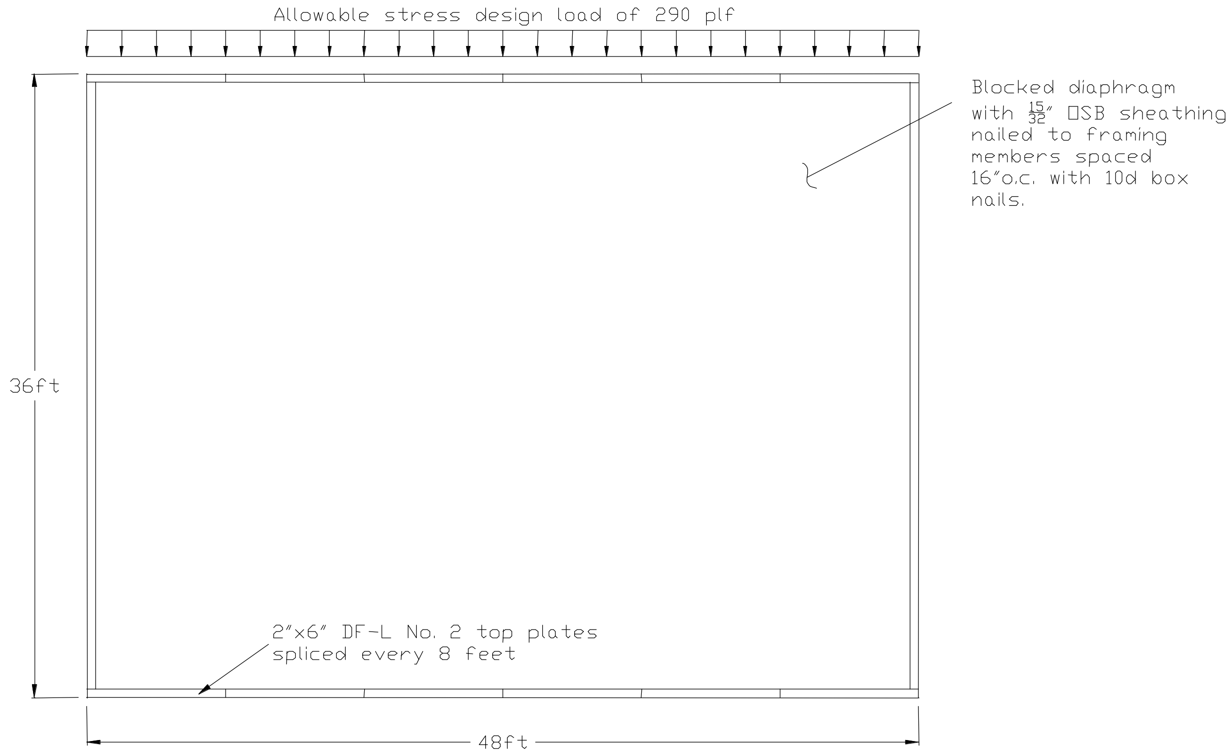
Other factors, such as the sheathing, will impact the bending component of diaphragm deflection as well. The sheathing acts as a web of a deep beam in diaphragm deflection calculations, yet it is common practice to ignore its contribution to the moment of inertia for the bending component of deflection. A separate calculation was done in this parametric study to show how much of the moment of inertia is *theoretically* ignored. In diaphragm systems that are glued and nailed, the sheathing may contribute a fair percentage of this theoretical additional moment of inertia. However, experimental studies would be necessary to quantify the exact contribution to overall moment of inertia.

For 2x4 top plate construction, the total theoretical moment of inertia including 0.375 in. thick sheathing was between 3.6 and 6.5 times the value that was actually used in the bending term of the diaphragm deflection equation, depending on diaphragm width. Naturally the 2x6 top plate has slightly lower values of 2.6 to 4.4 times the moment of inertia used. When 0.5 in. thick sheathing is employed, the 2x4 top plate yields values from 4.5 to 8.3 times the moment of inertia value that neglects the sheathing. Similarly, the 2x6 construction varies from 3.1 to 5.5 times the original value.

It is not recommended that the panel decking moment of inertia be used in the bending term, but simply demonstrates that the reserve stiffness could easily offset a less conservative assumption about chord area. How much the sheathing contributes, and thus how conservative the derived equation is, can depend on many factors, including the nailing schedule, joist spacing, use of adhesives, and the diaphragm size. Engineering judgment might suggest that the contribution of sheathing to the moment of inertia outweighs the lack of contribution in segments over the spliced chords. This deduction could easily suggest that for typical top plate 2x construction, the cross-sectional area of a two-ply member instead of a one-ply member be employed into the bending term of the diaphragm deflection equation.

Many example problems from other sources (Hoyle 1989, Breyer et. al. 2007, APA – The Engineered Wood Association 2007) tend to agree with this reasoning. Section 4.2.2 of the 2008 SDPWS defines “A” as the area of the chord cross-section in square inches, but by lack of specific information, leaves it up to engineering judgment to decide whether the chords are considered one ply or two plies. The consensus seems to show that the full chord area (e.g. two 2x4 pieces of lumber) can be used for the bending term.

Example Problem



Given: A 36-ft x 48-ft blocked wood structural diaphragm utilizing 8-ft lumber pieces for the 2x6 No. 2 DF-L chord members. Chord members are connected using 16d box nails. Sheathing is 15/32" OSB, nailed to framing spaced 16-in. on-center with 10d box nails.

Calculate: The number of nails required at each chord splice using ASD design loads from seismic and the mid-span deflection of the diaphragm due to seismic loads based on strength design loads in accordance with ASCE 7.

Part 1 – Number of nails required at each chord splice

The chords are connected using 16d box nails, therefore:
$D_{16d} = 0.135$ in. (NDS Table L4)
$Z_{16d} = 118$ lb/nail (NDS Table 11N)
$Z'_{16d} = 1.6(118\text{lb}) = 189$ lb/nail (NDS Table 10.3.1 – seismic load duration)

Assuming 6-in boundary and field spacing of nails, the diaphragm unit shear values for seismic are:
$v_s = 580\ plf$ (SDPWS Table 4.2A)

$$v_{s(ASD)} = \frac{v_s}{2} = 290\ plf$$

The maximum moment and axial chord forces, T or C, are then calculated:

$$w = \frac{2v_{s(ASD)}W}{L} = \frac{2(290\,plf)(36\,ft)}{48\,ft} = 435\,plf$$

$$M_{\max} = \frac{wL^2}{8} = \frac{435\,plf\,(48\,ft)^2}{8} = 125{,}280\,ft-lb$$

$$(T\,or\,C) = \frac{M_x}{W} = \frac{125{,}280\,ft-lb}{36\,ft} = 3480\,lb$$

The number of 16d box nails, n, is:

$$n = \frac{3480\,lb}{189\,lb/nail} = 19\,nails$$

This number is for each side of the splice joint. For different lumber lengths, the splices may not occur right at mid-span, and thus calculating a moment at that location instead of the maximum moment may be justifiable. For this example, a splice at mid-span was conservatively assumed.

Part 2 – Mid-span diaphragm deflection

Because ASCE 7 requires seismic story drift to be calculated using strength level design loads, the unit shears and chord forces must be calculated using those same loads. Therefore, for the diaphragm deflection equation, the loads must be multiplied by 1.4.

$v = 1.4(290\,plf) = 406\,plf$
$(T\,or\,C) = 1.4(3480\,lb) = 4872\,lb$

Mid-span diaphragm deflection is then calculated using the equation:

$$\delta_{dia} = \frac{5vL^3}{8EAW} + \frac{0.25vL}{1000G_a} + \frac{\sum x(\Delta_c)}{2W}$$

Term 1 – Bending

$$\delta_{dia(bending)} = \frac{5vL^3}{8EAW} = \frac{5(406\,plf)(48\,ft)^3}{8(1{,}600{,}000\,psi)(16.5\,in^2)(36\,ft)} = 0.030\,in$$

where:

L = 48 ft, diaphragm length
E = 1,600,000 psi, modulus of elasticity for No. 2 DF-L 2x6"chord member (NDS Supplement Table 4A)
A = 16.5 in^2, cross-sectional area of two 2x6 top plates
W = 36 ft, diaphragm width

For this example, full composite action of the two 2x6 top plates was assumed in *bending*. A cross-sectional area of one top plate would be used for the load carrying of axial forces in the chords, as the second top plate acts as a splice plate for axial loading.

Term 2 – Shear (panel shear and nail slip):

$$\delta_{dia(shear)} = \frac{0.25vL}{1000G_a} = \frac{0.25(406\,plf)(48\,ft)}{1000(25\,k/in)} = 0.195\,in$$

where:

G_a = 25 k/in, apparent diaphragm shear stiffness (SDPWS Table 4.2A)

Term 3 – Chord splice slip

$$\delta_{dia(chord\,splice)} = \frac{\sum x(\Delta_c)}{2W}$$

where:

x = the distance from each splice to the nearest support

Δ_c = joint deformation due to chord splice slip

$$\Delta_c = \frac{2(T\,or\,C)}{\gamma n} = \frac{2(4872\,lb)}{(8928\,lb/in/nail)(19\,nails)} = 0.057\,in$$

where:

γ = 8928 lb/in/nail, the load slip modulus for dowel-type fasteners (NDS Section 10.3.6), $\gamma = 180{,}000\ D^{1.5}$

A constant of 2 in the numerator is used to account for the slip on each side of the splice. The “D” value in the previous equation is the diameter of the fastener (although word for word is the diameter of the “bolt or lag screw”), which in this case is 0.135 in. for a 16d box nail.

Since the splices are identical for each chord (compression and tension), the summation becomes fairly straightforward:

$$\delta_{dia(chord\,splice)} = \frac{\sum x(\Delta_c)}{2W} = \frac{4(8\,ft)(0.057\,in) + 4(16\,ft)(0.057\,in) + 2(24\,ft)(0.057\,in)}{2(36\,ft)} = 0.115\,in$$

There are a total of four splices that are 8 feet away from the nearest support (end walls), four splices that are 16 feet away, and two splices that are 24 feet away (at mid-span). The Δ_c term is the same for each part of the summation.

Summing each of the deflection components results in:

$$\delta_{dia} = 0.030\,in + 0.195\,in + 0.115\,in = 0.340\,in$$

In this example, the chord slip term has a fairly large impact on the overall deflection because there are splices every 8 feet. This may often not be the case because lumber will often be much longer than 8 feet. The shear term is relatively small in this case because the G_a term is quite high due to the thick OSB sheathing instead of thinner plywood. In this case, the bending term contributes about 9% to the overall deflection, the shear term 57%, and the chord slip term is about 34%. Some other alternatives using this same diaphragm layout are:

Alternative 1:

The chord area is assumed to be that of one ply instead of two ($A = 8.25\ in^2$):

$$\delta_{dia} = 0.059in + 0.195in + 0.115in = 0.369in$$

Percentages:
Bending = 16%
Shear = 53%
Chord slip = 31%

Alternative 2:

Plywood sheathing instead of OSB (G_a term now equal to 15 k/in):

$$\delta_{dia} = 0.030in + 0.325in + 0.115in = 0.470in$$

Percentages:
Bending = 6%
Shear = 69%
Chord slip = 25%

Alternative 3:

Plywood sheathing, 8d nails instead of 10d, and 16’ lumber pieces:

$$\delta_{dia} = 0.027in + 0.477in + 0.051in = 0.555in$$

Percentages:
Bending = 5%
Shear = 86%
Chord slip = 9%

Alternative 4:

Unblocked diaphragm (G_a now equal to $0.4G_a$):

$$\delta_{dia} = 0.030in + 0.487in + 0.115in = 0.632in$$

Percentages:
Bending = 5%
Shear = 77%
Chord slip = 18%

Summary and Recommendations

An in-depth examination of the diaphragm deflection equation (AF&PA, 2008) was conducted to give insights to design professionals regarding the derivation and assumptions behind the equation. Historically, diaphragm deflection was not calculated, but the building size was instead limited to certain aspect ratios. Now diaphragms must meet certain requirements, such as seismic story drift. Furthermore, deflection of wood diaphragms with facades becomes important for the integrity of the building. Thus, the accurate calculation of the diaphragm deflection can be crucial. A brief summary of each of the three terms in the diaphragm deflection equation is given below.

The bending term accounts for flexural resistance of the chord framing, without taking any credit for the moment of inertia contributions of the diaphragm deck. The top plates of the wall are assumed to function as the diaphragm chords, yet a question remains as to what chord cross-sectional area should be used in calculations. After review of the parametric study and derivation of the bending term, the assumption of a two-ply chord member as the cross-sectional area results in 8% to 25% less deflection in the bending term than the actual calculated deflection from virtual work. However, as mentioned before, the contribution of the sheathing is neglected. If the sheathing is accounted for, and could achieve full composite action in the panels, the moment of inertia resisting the bending deflection becomes 2.5 to 8 times the moment of inertia actually used in the calculation. Realistically, the contribution of the sheathing would be somewhere in between the assumption of neglecting the sheathing and the assumption of the sheathing fully contributing.

The exploration of the shear term reveals information that engineers can also utilize when calculating wood diaphragm deflection. For simplicity, the use of the three-term diaphragm deflection equation is recommended. Utilizing tables from the 2008 SDPWS (AF&PA, 2008) make the calculation of the shear term quick and easy with the three-term equation, eliminating extra calculations. It is also noted that the APA recommends multiplying the overall diaphragm deflection by 2.5 for unblocked diaphragms. This recommendation would be overly conservative if the G_a term has already been reduced to take into account the unblocked diaphragm.

For the chord slip term it is recommended to utilize the 2008 SDPWS Commentary equation for Δ_c (found in the example problem) unless another assumption for the value can be justified. Furthermore, the slip in the compression chord should not be reduced to 1/6 that of the tension chord (previously recommended by the APA – The Engineered Wood Association, 2007) since there is no assurance that the members of the chord are tight (no gap) and have end grain bearing.

The sensitivity analysis seen in Appendix B shows how diaphragm size, sheathing type, lumber length in the chord, and the chord cross-sectional area affect how each of the three deflection terms contribute to the overall deflection. In general, a higher aspect ratio causes the bending portion to be a larger percent of the overall deflection. The designer should also be aware of how the sheathing and nailing schedule affects the shear portion of the overall deflection. By using Tables 4.2A through 4.2D in the 2008 SDPWS, the designer can reduce the deflection from shear by selecting a nailing schedule and sheathing type and thickness that results in a higher G_a value. The chord slip typically becomes a larger contributor to the overall deflection when shorter pieces of lumber are used because there are more splices, and thus more locations where the chord slips. The tables ultimately show that the shear term often contributes the largest percentage. However, the designer can have some influence on the overall deflection by their choice of material and chord cross-sectional area assumptions.

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Diaphragm Length (ft)	Ratio of virtual work calculated deflection for given end nail distance to deflection assuming one ply chord area 6"	4"	2.025"
40	**0.6256**	**0.5838**	**0.5425**
44	**0.6246**	**0.5831**	**0.5420**
48	**0.6254**	**0.5837**	**0.5424**
52	**0.6247**	**0.5831**	**0.5421**
56	**0.6253**	**0.5836**	**0.5423**
60	**0.6248**	**0.5832**	**0.5421**
64	**0.6253**	**0.5835**	**0.5423**
68	**0.6248**	**0.5832**	**0.5421**
72	**0.6252**	**0.5835**	**0.5423**
76	**0.6249**	**0.5832**	**0.5421**
80	**0.6252**	**0.5835**	**0.5423**

Table 1 – Deflection Ratio Calculations

Appendix A

The virtual work derivation used for this study came from the same derivation for that of a simply supported beam under a uniformly distributed load. From the figures below, the moments, *M* and *m*, along the first half of the beam can be calculated with respect to *x*, and then doubled due to symmetry of the beam and loading conditions. This is also the case for each diaphragm size that was evaluated because the nailing schedule was symmetric, and thus at mid-span of the diaphragm, there is either a splice, or the middle of an 8-ft top plate member. Calculating *M* and *m* with respect to *x* yields:

$$M = \frac{wLx}{2} - \frac{wx^2}{2}$$

$$m = \frac{x}{2}$$

The virtual work equation is given as:

$$\Delta = \int \frac{mM}{EI} dx$$

Substituting *m* and *M* into the equation (note the coefficient of 2 due to symmetry):

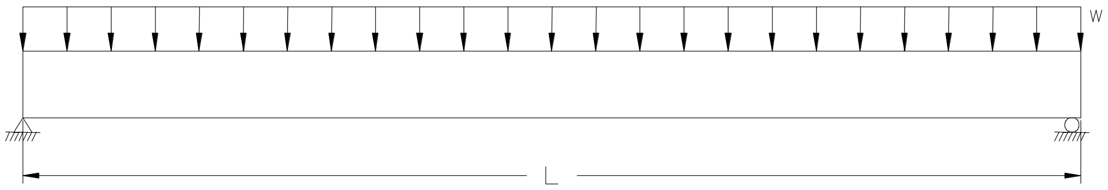
$$\Delta = 2\left(\frac{1}{EI}\right)\int_0^{L/2} \left[\frac{x}{2}\left(\frac{wLx}{2} - \frac{wx^2}{2}\right)\right] dx$$

$$\Delta = \frac{w}{2EI}\int_0^{L/2} \left(Lx^2 - x^3\right) dx$$

$$\Delta = \frac{w}{2EI}\left[\frac{Lx^3}{3} - \frac{x^4}{4}\right]_0^{L/2}$$

The above equation was utilized for different *x* values along the beam, and then summed over half the length of the beam. The value of *I*, which is the moment of inertia of the chords in this case, was doubled for the locations along the chord where it was assumed that the two plies act as one composite piece. These locations were described in depth in the *Virtual Work Analysis* section.

The overall summation for each end nail distance was then compared to the diaphragm deflection values calculated assuming the cross-sectional area of one ply of the top plate, which is summed up in Table 1. Full spreadsheets of these calculations are available from the author.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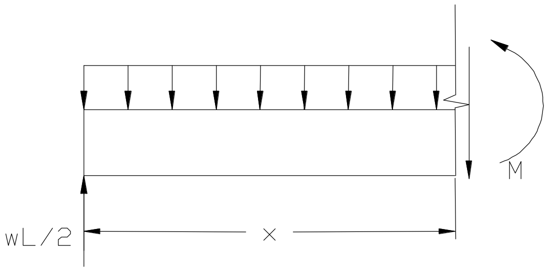
L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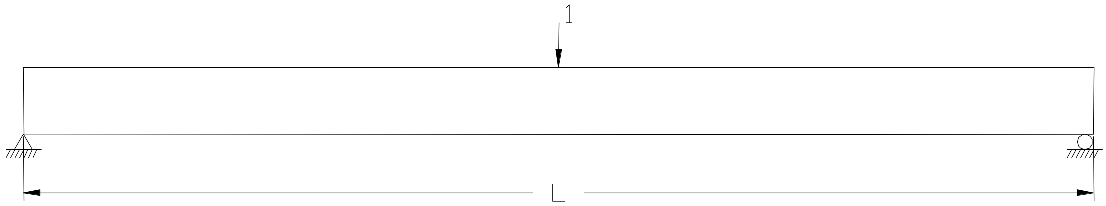
wL/2
x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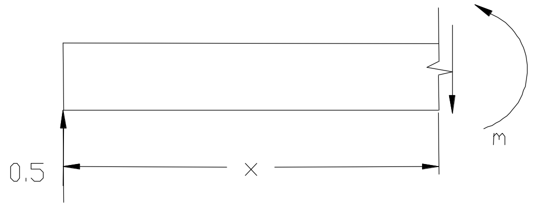
m
0.5
x

Appendix B

8' lumber pieces

20' diaphragm width

15/32" OSB sheathing

Top plate		L (ft)	Aspect ratio	Percentages			δ_{dia} (in)
				bending	**shear**	**chord slip**	
2x6	1 ply	40	2:1	**17.1**	**45.1**	**37.9**	0.360
		48	2.4:1	**20.9**	**38.3**	**40.7**	0.508
		56	2.8:1	**25.1**	**33.7**	**41.2**	0.674
		64	3.2:1	**28.5**	**29.4**	**42.1**	0.884
		72	3.6:1	**32.1**	**26.1**	**41.8**	1.118
		80	4:1	**35.1**	**23.1**	**41.8**	1.404
	2 ply	40	2:1	**9.3**	**49.3**	**41.4**	0.330
		48	2.4:1	**11.7**	**42.8**	**45.5**	0.455
		56	2.8:1	**14.3**	**38.6**	**47.1**	0.589
		64	3.2:1	**16.6**	**34.3**	**49.1**	0.758
		72	3.6:1	**19.1**	**31.1**	**49.8**	0.939
		80	4:1	**21.3**	**28.1**	**50.7**	1.158
		-	-	**-**	**-**	**-**	-
2x4	1 ply	40	2:1	**24.4**	**41.1**	**34.5**	0.395
		48	2.4:1	**29.4**	**34.3**	**36.4**	0.569
		56	2.8:1	**34.4**	**29.5**	**36**	0.770
		64	3.2:1	**38.5**	**25.3**	**36.2**	1.028
		72	3.6:1	**42.6**	**22.1**	**35.3**	1.323
		80	4:1	**45.9**	**19.3**	**34.8**	1.685
	2 ply	40	2:1	**13.9**	**46.8**	**39.3**	0.347
		48	2.4:1	**17.2**	**40.1**	**42.7**	0.485
		56	2.8:1	**20.8**	**35.7**	**43.5**	0.638
		64	3.2:1	**23.9**	**31.3**	**44.8**	0.830
		72	3.6:1	**27.1**	**28.1**	**44.9**	1.042
		80	4:1	**29.8**	**25**	**45.2**	1.298

7/16" Plywood sheathing

L (ft)	Aspect ratio	Percentages			δ_{dia} (in)
		bending	**shear**	**chord slip**	

2x6	1 ply	40	2:1	**9.9**	**65.2**	**24.9**	0.548
		48	2.4:1	**12.8**	**58.8**	**28.4**	0.729
		56	2.8:1	**16**	**54**	**30**	0.926
		64	3.2:1	**19**	**49**	**31.9**	1.165
		72	3.6:1	**22.1**	**45.1**	**32.8**	1.425
		80	4:1	**25**	**41.2**	**33.8**	1.733
	2 ply	40	2:1	**5.2**	**68.6**	**26.2**	0.520
		48	2.4:1	**6.9**	**62.8**	**30.4**	0.682
		56	2.8:1	**8.7**	**58.7**	**32.6**	0.852
		64	3.2:1	**10.5**	**54.2**	**35.3**	1.054
		72	3.6:1	**12.4**	**50.7**	**36.9**	1.268
		80	4:1	**14.3**	**47.1**	**38.7**	1.517
		-	-	**-**	**-**	**-**	-
2x4	1 ply	40	2:1	**14.7**	**61.7**	**23.6**	0.578
		48	2.4:1	**18.8**	**54.8**	**26.5**	0.782
		56	2.8:1	**23.1**	**49.5**	**27.5**	1.011
		64	3.2:1	**27**	**44.2**	**28.8**	1.291
		72	3.6:1	**30.9**	**40**	**29.1**	1.606
		80	4:1	**34.3**	**36**	**29.6**	1.981
	2 ply	40	2:1	**8.9**	**65.9**	**25.2**	0.542
		48	2.4:1	**11.6**	**59.6**	**28.8**	0.719
		56	2.8:1	**14.6**	**54.9**	**30.5**	0.910
		64	3.2:1	**17.3**	**50.1**	**32.6**	1.141
		72	3.6:1	**20.3**	**46.2**	**33.6**	1.392
		80	4:1	**22.9**	**42.3**	**34.8**	1.687

24' diaphragm width

15/32" OSB sheathing

				Percentages			
Top plate		L (ft)	Aspect ratio	**bending**	**shear**	**chord slip**	δ_{dia} (in)
2x6	1 ply	40	1.67:1	**15.7**	**49.6**	**34.7**	0.327
		48	2:1	**19.4**	**42.8**	**37.8**	0.456
		56	2.33:1	**23.4**	**37.9**	**38.7**	0.600
		64	2.67:1	**26.9**	**33.3**	**39.8**	0.781
		72	3:1	**30.5**	**29.8**	**39.7**	0.980
		80	3.33:1	**33.5**	**26.5**	**40**	1.224
	2 ply	40	1.67:1	**8.5**	**53.8**	**37.7**	0.302
		48	2:1	**10.8**	**47.4**	**41.9**	0.411
		56	2.33:1	**13.3**	**42.9**	**43.8**	0.530
		64	2.67:1	**15.5**	**38.4**	**46**	0.676
		72	3:1	**18**	**35.2**	**46.8**	0.831
		80	3.33:1	**20.1**	**31.9**	**48**	1.019
		-	-	**-**	**-**	**-**	-

2x4	1 ply	40	1.67:1	**22.6**	**45.5**	**31.9**	0.357
		48	2:1	**27.5**	**38.5**	**34**	0.506
		56	2.33:1	**32.5**	**33.4**	**34.1**	0.680
		64	2.67:1	**36.6**	**28.8**	**34.5**	0.901
		72	3:1	**40.8**	**25.4**	**33.8**	1.151
		80	3.33:1	**44.2**	**22.3**	**33.5**	1.458
	2 ply	40	1.67:1	**12.7**	**51.3**	**35.9**	0.316
		48	2:1	**15.9**	**44.6**	**39.5**	0.437
		56	2.33:1	**19.4**	**39.9**	**40.7**	0.570
		64	2.67:1	**22.4**	**35.3**	**42.3**	0.736
		72	3:1	**25.6**	**31.9**	**42.5**	0.916
		80	3.33:1	**28.4**	**28.6**	**43**	1.136

7/16" Plywood sheathing

				Percentages			
		L (ft)	Aspect ratio	**bending**	**shear**	**chord slip**	δ_{dia} (in)
2x6	1 ply	40	1.67:1	**8.7**	**69.2**	**22**	0.516
		48	2:1	**11.5**	**63.1**	**25.4**	0.679
		56	2.33:1	**14.5**	**58.4**	**27.1**	0.855
		64	2.67:1	**17.3**	**53.5**	**29.2**	1.067
		72	3:1	**20.3**	**49.6**	**30.1**	1.295
		80	3.33:1	**23.1**	**45.7**	**31.3**	1.564
	2 ply	40	1.67:1	**4.6**	**72.4**	**23**	0.493
		48	2:1	**6.1**	**67**	**26.9**	0.640
		56	2.33:1	**7.8**	**63**	**29.2**	0.794
		64	2.67:1	**9.5**	**58.6**	**31.9**	0.975
		72	3:1	**11.3**	**55.2**	**33.5**	1.163
		80	3.33:1	**13**	**51.6**	**35.3**	1.383
		-	-				-
2x4	1 ply	40	1.67:1	**13.1**	**65.9**	**21**	0.542
		48	2:1	**16.9**	**59.2**	**23.8**	0.723
		56	2.33:1	**21**	**54**	**25**	0.926
		64	2.67:1	**24.7**	**48.7**	**26.5**	1.172
		72	3:1	**28.6**	**44.5**	**26.9**	1.445
		80	3.33:1	**32**	**40.3**	**27.6**	1.770
	2 ply	40	1.67:1	**7.9**	**69.9**	**22.2**	0.511
		48	2:1	**10.4**	**63.9**	**25.7**	0.670
		56	2.33:1	**13.1**	**59.3**	**27.5**	0.842
		64	2.67:1	**15.8**	**54.5**	**29.7**	1.047
		72	3:1	**18.5**	**50.7**	**30.7**	1.267
		80	3.33:1	**21.1**	**46.8**	**32.1**	1.525

28' diaphragm width

15/32" OSB sheathing

Top plate		L (ft)	Aspect ratio	Percentages			δ_{dia} (in)
				bending	**shear**	**chord slip**	
2x6	1 ply	40	1.43:1	**14.5**	**53.5**	**32.1**	0.304
		48	1.71:1	**18.1**	**46.6**	**35.3**	0.418
		56	2:1	**22.1**	**41.6**	**36.3**	0.546
		64	2.29:1	**25.5**	**36.8**	**37.7**	0.706
		72	2.57:1	**29**	**33.1**	**37.9**	0.883
		80	2.86:1	**32.1**	**29.7**	**38.3**	1.095
	2 ply	40	1.43:1	**7.8**	**57.6**	**34.6**	0.282
		48	1.71:1	**10**	**51.2**	**38.8**	0.380
		56	2:1	**12.4**	**46.8**	**40.8**	0.486
		64	2.29:1	**14.6**	**42.2**	**43.2**	0.616
		72	2.57:1	**17**	**38.7**	**44.3**	0.755
		80	2.86:1	**19.1**	**35.3**	**45.6**	0.920
		-	-	**-**	**-**	**-**	-
2x4	1 ply	40	1.43:1	**21**	**49.4**	**29.6**	0.329
		48	1.71:1	**25.8**	**42.2**	**32**	0.462
		56	2:1	**30.8**	**37**	**32.3**	0.615
		64	2.29:1	**35**	**32.1**	**32.9**	0.809
		72	2.57:1	**39.1**	**28.4**	**32.5**	1.030
		80	2.86:1	**42.6**	**25.1**	**32.3**	1.296
	2 ply	40	1.43:1	**11.7**	**55.2**	**33.1**	0.294
		48	1.71:1	**14.8**	**48.5**	**36.7**	0.402
		56	2:1	**18.2**	**43.7**	**38.1**	0.521
		64	2.29:1	**21.2**	**38.9**	**39.9**	0.668
		72	2.57:1	**24.3**	**35.3**	**40.4**	0.828
		80	2.86:1	**27.1**	**31.8**	**41.1**	1.020

7/16" Plywood sheathing

		L (ft)	Aspect ratio	Percentages			δ_{dia} (in)
				bending	**shear**	**chord slip**	
2x6	1 ply	40	1.43:1	**7.8**	**72.4**	**19.8**	0.493
		48	1.71:1	**10.4**	**66.7**	**23**	0.643
		56	2:1	**13.2**	**62.1**	**24.7**	0.804
		64	2.29:1	**15.9**	**57.4**	**26.7**	0.996
		72	2.57:1	**18.7**	**53.4**	**27.8**	1.203
		80	2.86:1	**21.4**	**49.5**	**29.1**	1.442
	2 ply	40	1.43:1	**4.1**	**75.4**	**20.6**	0.474
		48	1.71:1	**5.5**	**70.3**	**24.2**	0.609
		56	2:1	**7.1**	**66.5**	**26.4**	0.751
		64	2.29:1	**8.6**	**62.3**	**29.1**	0.917
		72	2.57:1	**10.3**	**59**	**30.7**	1.090

		80	2.86:1	**12**	**55.4**	**32.5**	1.288
		-	-				-
2x4	1 ply	40	1.43:1	**11.8**	**69.3**	**18.9**	0.515
		48	1.71:1	**15.4**	**62.9**	**21.7**	0.681
		56	2:1	**19.3**	**57.8**	**22.9**	0.865
		64	2.29:1	**22.9**	**52.6**	**24.5**	1.086
		72	2.57:1	**26.6**	**48.3**	**25.1**	1.331
		80	2.86:1	**30**	**44.1**	**25.9**	1.619
	2 ply	40	1.43:1	**7.1**	**73**	**19.9**	0.489
		48	1.71:1	**9.4**	**67.4**	**23.2**	0.636
		56	2:1	**11.9**	**63**	**25**	0.793
		64	2.29:1	**14.4**	**58.3**	**27.2**	0.979
		72	2.57:1	**17.1**	**54.5**	**28.4**	1.179
		80	2.86:1	**19.6**	**50.7**	**29.7**	1.409

32' diaphragm width

15/32" OSB sheathing

				Percentages			
Top plate		L (ft)	Aspect ratio	**bending**	**shear**	**chord slip**	δ_{dia} (in)
2x6	1 ply	40	1.25:1	**13.4**	**56.8**	**29.8**	0.286
		48	1.5:1	**17**	**49.9**	**33.1**	0.391
		56	1.75:1	**20.8**	**44.9**	**34.3**	0.506
		64	2:1	**24.2**	**40**	**35.8**	0.650
		72	2.25:1	**27.7**	**36.1**	**36.2**	0.809
		80	2.5:1	**30.8**	**32.5**	**36.7**	0.999
	2 ply	40	1.25:1	**7.2**	**60.9**	**31.9**	0.267
		48	1.5:1	**9.3**	**54.5**	**36.2**	0.357
		56	1.75:1	**11.6**	**50.1**	**38.2**	0.454
		64	2:1	**13.8**	**45.5**	**40.7**	0.571
		72	2.25:1	**16.1**	**41.9**	**42**	0.697
		80	2.5:1	**18.2**	**38.4**	**43.4**	0.845
		-	-	**-**	**-**	**-**	-
2x4	1 ply	40	1.25:1	**19.6**	**52.7**	**27.7**	0.308
		48	1.5:1	**24.4**	**45.5**	**30.2**	0.429
		56	1.75:1	**29.3**	**40.1**	**30.6**	0.567
		64	2:1	**33.4**	**35.1**	**31.5**	0.740
		72	2.25:1	**37.6**	**31.2**	**31.2**	0.937
		80	2.5:1	**41.1**	**27.6**	**31.2**	1.175
	2 ply	40	1.25:1	**10.9**	**58.4**	**30.7**	0.278
		48	1.5:1	**13.9**	**51.8**	**34.4**	0.376
		56	1.75:1	**17.1**	**47**	**35.9**	0.484
		64	2:1	**20.1**	**42.2**	**37.8**	0.616
		72	2.25:1	**23.1**	**38.4**	**38.4**	0.761

		80	2.5:1	**25.9**	**34.8**	**39.3**	0.933

7/16" Plywood sheathing

				Percentages			
		L (ft)	Aspect ratio	**bending**	**shear**	**chord slip**	δ_{dia} (in)
2x6	1 ply	40	1.25:1	**7.1**	**75**	**17.9**	0.476
		48	1.5:1	**9.5**	**69.5**	**21**	0.616
		56	1.75:1	**12.1**	**65.3**	**22.6**	0.766
		64	2:1	**14.7**	**60.6**	**24.7**	0.942
		72	2.25:1	**17.4**	**56.7**	**25.8**	1.132
		80	2.5:1	**20**	**52.8**	**27.1**	1.351
	2 ply	40	1.25:1	**3.7**	**77.7**	**18.6**	0.459
		48	1.5:1	**5**	**73**	**22**	0.587
		56	1.75:1	**6.4**	**69.5**	**24.1**	0.720
		64	2:1	**7.9**	**65.4**	**26.7**	0.873
		72	2.25:1	**9.5**	**62.2**	**28.3**	1.034
		80	2.5:1	**11.1**	**58.7**	**30.2**	1.216
		-	-				-
2x4	1 ply	40	1.25:1	**10.7**	**72.1**	**17.2**	0.495
		48	1.5:1	**14.1**	**66**	**19.9**	0.650
		56	1.75:1	**17.8**	**61**	**21.2**	0.819
		64	2:1	**21.3**	**55.9**	**22.8**	1.022
		72	2.25:1	**24.9**	**51.6**	**23.5**	1.245
		80	2.5:1	**28.2**	**47.4**	**24.4**	1.506
	2 ply	40	1.25:1	**6.4**	**75.6**	**18**	0.472
		48	1.5:1	**8.6**	**70.2**	**21.2**	0.610
		56	1.75:1	**11**	**66.1**	**22.9**	0.756
		64	2:1	**13.3**	**61.6**	**25.1**	0.928
		72	2.25:1	**15.9**	**57.8**	**26.3**	1.111
		80	2.5:1	**18.3**	**54**	**27.7**	1.322

36' diaphragm width

15/32" OSB sheathing

				Percentages			
Top plate		L (ft)	Aspect ratio	**bending**	**shear**	**chord slip**	δ_{dia} (in)
2x6	1 ply	40	1.11:1	**12.5**	**59.6**	**27.8**	0.272
		48	1.33:1	**16**	**52.8**	**31.1**	0.369
		56	1.56:1	**19.7**	**47.8**	**32.5**	0.476
		64	1.78:1	**23.1**	**42.8**	**34.1**	0.607
		72	2:1	**26.5**	**38.9**	**34.6**	0.751

		80	2.22:1	**29.6**	**35.1**	**35.3**	0.924
	2 ply	40	1.11:1	**6.7**	**63.6**	**29.7**	0.255
		48	1.33:1	**8.7**	**57.4**	**33.9**	0.339
		56	1.56:1	**10.9**	**53**	**36**	0.429
		64	1.78:1	**13**	**48.4**	**38.5**	0.537
		72	2:1	**15.3**	**44.8**	**39.9**	0.652
		80	2.22:1	**17.4**	**41.2**	**41.4**	0.787
		-	-	-	-	-	-
2x4	1 ply	40	1.11:1	**18.4**	**55.6**	**26**	0.292
		48	1.33:1	**23.1**	**48.4**	**28.5**	0.403
		56	1.56:1	**27.9**	**43**	**29.2**	0.529
		64	1.78:1	**32**	**37.8**	**30.1**	0.687
		72	2:1	**36.2**	**33.8**	**30**	0.865
		80	2.22:1	**39.8**	**30.1**	**30.2**	1.080
	2 ply	40	1.11:1	**10.1**	**61.3**	**28.6**	0.265
		48	1.33:1	**13**	**54.7**	**32.3**	0.356
		56	1.56:1	**16.2**	**49.9**	**33.9**	0.455
		64	1.78:1	**19.1**	**45.1**	**35.9**	0.577
		72	2:1	**22.1**	**41.2**	**36.7**	0.709
		80	2.22:1	**24.8**	**37.5**	**37.7**	0.866

7/16" Plywood sheathing

				Percentages			
		L (ft)	Aspect ratio	**bending**	**shear**	**chord slip**	δ_{dia} (in)
2x6	1 ply	40	1.11:1	**6.5**	**77.1**	**16.4**	0.463
		48	1.33:1	**8.7**	**72**	**19.3**	0.595
		56	1.56:1	**11.2**	**67.8**	**21**	0.737
		64	1.78:1	**13.7**	**63.4**	**22.9**	0.901
		72	2:1	**16.3**	**59.6**	**24.1**	1.078
		80	2.22:1	**18.8**	**55.8**	**25.5**	1.280
	2 ply	40	1.11:1	**3.4**	**79.7**	**16.9**	0.448
		48	1.33:1	**4.6**	**75.3**	**20.2**	0.569
		56	1.56:1	**5.9**	**71.9**	**22.2**	0.695
		64	1.78:1	**7.3**	**68**	**24.6**	0.840
		72	2:1	**8.9**	**64.9**	**26.2**	0.990
		80	2.22:1	**10.4**	**61.5**	**28.1**	1.160
		-	-				-
2x4	1 ply	40	1.11:1	**9.8**	**74.4**	**15.8**	0.480
		48	1.33:1	**13.1**	**68.6**	**18.4**	0.625
		56	1.56:1	**16.5**	**63.8**	**19.7**	0.784
		64	1.78:1	**19.9**	**58.8**	**21.3**	0.971
		72	2:1	**23.4**	**54.6**	**22.1**	1.178
		80	2.22:1	**26.6**	**50.4**	**23**	1.418
	2 ply	40	1.11:1	**5.8**	**77.7**	**16.5**	0.460
		48	1.33:1	**7.9**	**72.6**	**19.5**	0.590
		56	1.56:1	**10.1**	**68.7**	**21.2**	0.728

		64	1.78:1	**12.4**	**64.3**	**23.3**	0.888
		72	2:1	**14.8**	**60.7**	**24.5**	1.059
		80	2.22:1	**17.1**	**56.9**	**26**	1.255

40' diaphragm width

15/32" OSB sheathing

				Percentages			
Top plate		L (ft)	Aspect ratio	**bending**	**shear**	**chord slip**	δ_{dia} (in)
2x6	1 ply	40	1:1	**11.8**	**62.1**	**26.1**	0.261
		48	1.2:1	**15.1**	**55.5**	**29.4**	0.351
		56	1.4:1	**18.7**	**50.5**	**30.8**	0.451
		64	1.6:1	**22**	**45.4**	**32.6**	0.572
		72	1.8:1	**25.4**	**41.4**	**33.1**	0.705
		80	2:1	**28.5**	**37.6**	**33.9**	0.864
	2 ply	40	1:1	**6.3**	**66**	**27.7**	0.246
		48	1.2:1	**8.2**	**60**	**31.8**	0.325
		56	1.4:1	**10.3**	**55.7**	**34**	0.408
		64	1.6:1	**12.4**	**51**	**36.6**	0.509
		72	1.8:1	**14.6**	**47.5**	**38**	0.616
		80	2:1	**16.6**	**43.8**	**39.6**	0.741
		-	-	-	-	-	-
2x4	1 ply	40	1:1	**17.3**	**58.2**	**24.5**	0.279
		48	1.2:1	**21.9**	**51.1**	**27.1**	0.382
		56	1.4:1	**26.6**	**45.6**	**27.8**	0.499
		64	1.6:1	**30.7**	**40.3**	**28.9**	0.644
		72	1.8:1	**34.9**	**36.2**	**28.9**	0.808
		80	2:1	**38.5**	**32.3**	**29.2**	1.005
	2 ply	40	1:1	**9.5**	**63.7**	**26.8**	0.255
		48	1.2:1	**12.3**	**57.3**	**30.4**	0.340
		56	1.4:1	**15.3**	**52.6**	**32.1**	0.432
		64	1.6:1	**18.2**	**47.6**	**34.2**	0.545
		72	1.8:1	**21.1**	**43.8**	**35**	0.667
		80	2:1	**23.8**	**40**	**36.2**	0.812

7/16" Plywood sheathing

				Percentages			
		L (ft)	Aspect ratio	**bending**	**shear**	**chord slip**	δ_{dia} (in)
2x6	1 ply	40	1:1	**6**	**78.9**	**15.1**	0.452
		48	1.2:1	**8.1**	**74.1**	**17.9**	0.578
		56	1.4:1	**10.4**	**70.1**	**19.5**	0.713

		64	1.6:1	**12.8**	**65.8**	**21.5**	0.868
		72	1.8:1	**15.3**	**62.1**	**22.6**	1.034
		80	2:1	**17.7**	**58.3**	**24**	1.224
	2 ply	40	1:1	**3.1**	**81.4**	**15.5**	0.439
		48	1.2:1	**4.2**	**77.2**	**18.6**	0.555
		56	1.4:1	**5.5**	**74**	**20.5**	0.676
		64	1.6:1	**6.8**	**70.2**	**22.9**	0.813
		72	1.8:1	**8.3**	**67.3**	**24.5**	0.955
		80	2:1	**9.7**	**64**	**26.3**	1.116
		-	-				-
2x4	1 ply	40	1:1	**9.1**	**76.3**	**14.6**	0.468
		48	1.2:1	**12.1**	**70.8**	**17.1**	0.605
		56	1.4:1	**15.4**	**66.2**	**18.4**	0.755
		64	1.6:1	**18.7**	**61.3**	**20**	0.932
		72	1.8:1	**22**	**57.2**	**20.8**	1.124
		80	2:1	**25.2**	**53**	**21.8**	1.347
	2 ply	40	1:1	**5.4**	**79.4**	**15.2**	0.449
		48	1.2:1	**7.3**	**74.7**	**18**	0.573
		56	1.4:1	**9.4**	**70.9**	**19.7**	0.705
		64	1.6:1	**11.6**	**66.7**	**21.8**	0.857
		72	1.8:1	**13.9**	**63.2**	**23**	1.017
		80	2:1	**16.1**	**59.5**	**24.4**	1.201

Min %	3.1	19.3	14.6
Max %	45.9	81.4	50.7
Avg %	17.9	51.6	30.5

16' lumber pieces

20' diaphragm width

15/32" OSB sheathing

Top plate		L (ft)	Aspect ratio	Percentages			δ_{dia} (in)
				bending	**shear**	**chord slip**	
2x6	1 ply	40	2:1	**21.1**	**55.6**	**23.3**	0.292
		48	2.4:1	**27**	**49.6**	**23.4**	0.393
		56	2.8:1	**31.6**	**42.5**	**25.9**	0.535
		64	3.2:1	**36.1**	**37.2**	**26.7**	0.698
		72	3.6:1	**40.5**	**33**	**26.4**	0.885
		80	4:1	**44.8**	**29.6**	**25.6**	1.099

	2 ply	40	2:1	**11.8**	**62.1**	**26.1**	0.261
		48	2.4:1	**15.6**	**57.3**	**27.1**	0.340
		56	2.8:1	**18.7**	**50.5**	**30.8**	0.451
		64	3.2:1	**22**	**45.4**	**32.5**	0.572
		72	3.6:1	**25.4**	**41.4**	**33.1**	0.705
		80	4:1	**28.9**	**38.1**	**33**	0.852
		-	-	-	-	-	-
2x4	1 ply	40	2:1	**29.5**	**49.6**	**20.8**	0.327
		48	2.4:1	**36.8**	**42.9**	**20.3**	0.454
		56	2.8:1	**42**	**36**	**22**	0.631
		64	3.2:1	**47**	**30.9**	**22.1**	0.842
		72	3.6:1	**51.7**	**26.8**	**21.4**	1.090
		80	4:1	**56**	**23.5**	**20.4**	1.380
	2 ply	40	2:1	**17.3**	**58.2**	**24.5**	0.279
		48	2.4:1	**22.5**	**52.6**	**24.8**	0.370
		56	2.8:1	**26.6**	**45.6**	**27.8**	0.499
		64	3.2:1	**30.8**	**40.4**	**28.9**	0.644
		72	3.6:1	**34.9**	**36.2**	**28.9**	0.808
		80	4:1	**38.9**	**32.7**	**28.4**	0.993

7/16" Plywood sheathing

				Percentages			
		L (ft)	Aspect ratio	**bending**	**shear**	**chord slip**	δ_{dia} (in)
2x6	1 ply	40	2:1	**11.3**	**74.5**	**14.2**	0.479
		48	2.4:1	**15.2**	**69.8**	**15**	0.614
		56	2.8:1	**18.9**	**63.5**	**17.6**	0.787
		64	3.2:1	**22.6**	**58.4**	**19**	0.979
		72	3.6:1	**26.5**	**53.9**	**19.6**	1.192
		80	4:1	**30.3**	**50**	**19.7**	1.428
	2 ply	40	2:1	**6**	**78.9**	**15.1**	0.452
		48	2.4:1	**8.2**	**75.5**	**16.2**	0.567
		56	2.8:1	**10.4**	**70.1**	**19.5**	0.713
		64	3.2:1	**12.8**	**65.8**	**21.4**	0.868
		72	3.6:1	**15.3**	**62.1**	**22.6**	1.034
		80	4:1	**17.9**	**58.9**	**23.2**	1.212
		-	-	-	-	-	-
2x4	1 ply	40	2:1	**16.7**	**70**	**13.4**	0.510
		48	2.4:1	**22**	**64.2**	**13.8**	0.667
		56	2.8:1	**26.8**	**57.3**	**15.9**	0.872
		64	3.2:1	**31.5**	**51.7**	**16.8**	1.105
		72	3.6:1	**36.1**	**46.8**	**17**	1.372
		80	4:1	**40.6**	**42.6**	**16.8**	1.676
	2 ply	40	2:1	**10.2**	**75.4**	**14.4**	0.474
		48	2.4:1	**13.8**	**70.9**	**15.2**	0.604
		56	2.8:1	**17.2**	**64.8**	**18**	0.771
		64	3.2:1	**20.7**	**59.8**	**19.5**	0.955

		72	3.6:1	**24.3**	**55.5**	**20.2**	1.158
		80	4:1	**28**	**51.7**	**20.4**	1.382

24' diaphragm width

15/32" OSB sheathing

Top plate		L (ft)	Aspect ratio	Percentages			δ_{dia} (in)
				bending	**shear**	**chord slip**	
2x6	1 ply	40	1.67:1	**19**	**60**	**21**	0.271
		48	2:1	**24.6**	**54.1**	**21.3**	0.360
		56	2.33:1	**29.1**	**47**	**24**	0.484
		64	2.67:1	**33.6**	**41.5**	**24.9**	0.625
		72	3:1	**38**	**37.2**	**24.8**	0.786
		80	3.33:1	**42.3**	**33.5**	**24.2**	0.970
	2 ply	40	1.67:1	**10.5**	**66.3**	**23.2**	0.245
		48	2:1	**14**	**61.7**	**24.3**	0.316
		56	2.33:1	**17**	**55**	**28**	0.414
		64	2.67:1	**20.2**	**49.9**	**29.9**	0.520
		72	3:1	**23.5**	**45.9**	**30.6**	0.636
		80	3.33:1	**26.8**	**42.5**	**30.7**	0.765
		-	-	**-**	**-**	**-**	-
2x4	1 ply	40	1.67:1	**26.9**	**54.2**	**19**	0.300
		48	2:1	**33.9**	**47.5**	**18.6**	0.411
		56	2.33:1	**39.2**	**40.3**	**20.5**	0.564
		64	2.67:1	**44.3**	**34.9**	**20.9**	0.745
		72	3:1	**49.1**	**30.6**	**20.3**	0.957
		80	3.33:1	**53.5**	**27**	**19.5**	1.204
	2 ply	40	1.67:1	**15.5**	**62.6**	**21.9**	0.260
		48	2:1	**20.4**	**57.1**	**22.5**	0.341
		56	2.33:1	**24.4**	**50.1**	**25.5**	0.454
		64	2.67:1	**28.4**	**44.8**	**26.8**	0.580
		72	3:1	**32.5**	**40.5**	**27**	0.722
		80	3.33:1	**36.5**	**36.8**	**26.6**	0.882

7/16" Plywood sheathing

		L (ft)	Aspect ratio	Percentages			δ_{dia} (in)
				bending	**shear**	**chord slip**	
2x6	1 ply	40	1.67:1	**9.8**	**77.8**	**12.4**	0.459
		48	2:1	**13.4**	**73.5**	**13.1**	0.583
		56	2.33:1	**16.7**	**67.6**	**15.7**	0.739
		64	2.67:1	**20.3**	**62.7**	**17.1**	0.911

		72	3:1	**23.9**	**58.4**	**17.7**	1.100
		80	3.33:1	**27.5**	**54.5**	**17.9**	1.309
	2 ply	40	1.67:1	**5.2**	**81.8**	**13**	0.436
		48	2:1	**7.2**	**78.8**	**14.1**	0.544
		56	2.33:1	**9.1**	**73.8**	**17.1**	0.678
		64	2.67:1	**11.3**	**69.7**	**19**	0.819
		72	3:1	**13.6**	**66.3**	**20.1**	0.969
		80	3.33:1	**16**	**63.2**	**20.8**	1.129
		-	-				-
2x4	1 ply	40	1.67:1	**14.6**	**73.7**	**11.7**	0.515
		48	2:1	**19.5**	**68.3**	**12.2**	0.681
		56	2.33:1	**24**	**61.7**	**14.3**	0.865
		64	2.67:1	**28.5**	**56.2**	**15.3**	1.086
		72	3:1	**33**	**51.4**	**15.6**	1.331
		80	3.33:1	**37.4**	**47.1**	**15.5**	1.619
	2 ply	40	1.67:1	**8.9**	**78.6**	**12.5**	0.454
		48	2:1	**12.1**	**74.6**	**13.3**	0.575
		56	2.33:1	**15.2**	**68.8**	**16**	0.726
		64	2.67:1	**18.5**	**64.1**	**17.4**	0.892
		72	3:1	**21.9**	**59.9**	**18.1**	1.072
		80	3.33:1	**25.4**	**56.2**	**18.5**	1.271

28' diaphragm width

15/32" OSB sheathing

			Aspect ratio	**Percentages**			
Top plate		L (ft)		**bending**	**shear**	**chord slip**	δ_{dia} (in)
2x6	1 ply	40	1.43:1	**17.2**	**63.7**	**19.1**	0.255
		48	1.71:1	**22.6**	**57.9**	**19.5**	0.336
		56	2:1	**27**	**50.8**	**22.2**	0.447
		64	2.29:1	**31.4**	**45.3**	**23.2**	0.573
		72	2.57:1	**35.8**	**40.8**	**23.4**	0.716
		80	2.86:1	**40.1**	**37**	**22.9**	0.877
	2 ply	40	1.43:1	**9.4**	**69.7**	**20.9**	0.233
		48	1.71:1	**12.7**	**65.3**	**22**	0.298
		56	2:1	**15.6**	**58.8**	**25.6**	0.387
		64	2.29:1	**18.6**	**53.8**	**27.6**	0.483
		72	2.57:1	**21.8**	**49.7**	**28.5**	0.588
		80	2.86:1	**25**	**46.3**	**28.7**	0.702
		-	-	**-**	**-**	**-**	-
2x4	1 ply	40	1.43:1	**24.6**	**58**	**17.4**	0.280
		48	1.71:1	**31.4**	**51.3**	**17.3**	0.380
		56	2:1	**36.7**	**44.1**	**19.2**	0.516
		64	2.29:1	**41.8**	**38.4**	**19.7**	0.676

		72	2.57:1	**46.7**	**33.9**	**19.4**	0.862
		80	2.86:1	**51.2**	**30.1**	**18.7**	1.078
	2 ply	40	1.43:1	**14.1**	**66.1**	**19.8**	0.246
		48	1.71:1	**18.6**	**60.9**	**20.5**	0.320
		56	2:1	**22.5**	**54**	**23.5**	0.421
		64	2.29:1	**26.5**	**48.6**	**24.9**	0.534
		72	2.57:1	**30.5**	**44.2**	**25.3**	0.661
		80	2.86:1	**34.4**	**40.5**	**25.1**	0.802

7/16" Plywood sheathing

		L (ft)	Aspect ratio	**Percentages**			δ_{dia} (in)
				bending	**shear**	**chord slip**	
2x6	1 ply	40	1.43:1	**8.7**	**80.3**	**11**	0.444
		48	1.71:1	**11.9**	**76.4**	**11.7**	0.561
		56	2:1	**15**	**70.9**	**14.1**	0.705
		64	2.29:1	**18.3**	**66.2**	**15.4**	0.863
		72	2.57:1	**21.8**	**62.1**	**16.2**	1.035
		80	2.86:1	**25.2**	**58.3**	**16.4**	1.224
	2 ply	40	1.43:1	**4.5**	**84**	**11.5**	0.425
		48	1.71:1	**6.3**	**81.2**	**12.4**	0.527
		56	2:1	**8.1**	**76.7**	**15.2**	0.652
		64	2.29:1	**10.1**	**72.9**	**17**	0.783
		72	2.57:1	**12.2**	**69.6**	**18.1**	0.923
		80	2.86:1	**14.4**	**66.7**	**18.8**	1.070
		-	-				-
2x4	1 ply	40	1.43:1	**13**	**76.5**	**10.4**	0.466
		48	1.71:1	**17.5**	**71.5**	**11**	0.599
		56	2:1	**21.8**	**65.3**	**13**	0.766
		64	2.29:1	**26.1**	**59.9**	**14**	0.953
		72	2.57:1	**30.4**	**55.2**	**14.4**	1.164
		80	2.86:1	**34.7**	**51**	**14.4**	1.401
	2 ply	40	1.43:1	**7.8**	**81.1**	**11.1**	0.440
		48	1.71:1	**10.8**	**77.4**	**11.8**	0.554
		56	2:1	**13.7**	**72**	**14.3**	0.694
		64	2.29:1	**16.7**	**67.5**	**15.7**	0.846
		72	2.57:1	**19.9**	**63.5**	**16.5**	1.011
		80	2.86:1	**23.2**	**59.9**	**16.9**	1.191

32' diaphragm width

15/32" OSB sheathing

	Aspect	**Percentages**	δ_{dia} (in)

Top plate		L (ft)	ratio	bending	shear	chord slip	
2x6	1 ply	40	1.25:1	**15.8**	**66.7**	**17.5**	0.243
		48	1.5:1	**20.8**	**61.1**	**18**	0.319
		56	1.75:1	**25.1**	**54.2**	**20.7**	0.420
		64	2:1	**29.5**	**48.7**	**21.8**	0.534
		72	2.25:1	**33.8**	**44.1**	**22.1**	0.663
		80	2.5:1	**38**	**40.2**	**21.8**	0.808
	2 ply	40	1.25:1	**8.6**	**72.4**	**19**	0.224
		48	1.5:1	**11.6**	**68.2**	**20.1**	0.286
		56	1.75:1	**14.4**	**62**	**23.6**	0.367
		64	2:1	**17.3**	**57.1**	**25.6**	0.455
		72	2.25:1	**20.4**	**53.1**	**26.6**	0.551
		80	2.5:1	**23.5**	**49.6**	**26.9**	0.655
		-	-	-	-	-	-
2x4	1 ply	40	1.25:1	**22.8**	**61.2**	**16.1**	0.265
		48	1.5:1	**29.3**	**54.6**	**16.1**	0.357
		56	1.75:1	**34.5**	**47.4**	**18.1**	0.480
		64	2:1	**39.7**	**41.7**	**18.7**	0.624
		72	2.25:1	**44.5**	**37**	**18.5**	0.791
		80	2.5:1	**49.1**	**33**	**17.9**	0.984
	2 ply	40	1.25:1	**12.8**	**69**	**18.1**	0.235
		48	1.5:1	**17.1**	**64**	**18.9**	0.305
		56	1.75:1	**20.9**	**57.3**	**21.8**	0.397
		64	2:1	**24.7**	**52**	**23.3**	0.500
		72	2.25:1	**28.7**	**47.5**	**23.8**	0.615
		80	2.5:1	**32.5**	**43.7**	**23.7**	0.742

7/16" Plywood sheathing

				Percentages			
		L (ft)	Aspect ratio	bending	shear	chord slip	δ_{dia} (in)
2x6	1 ply	40	1.25:1	**7.8**	**82.4**	**9.8**	0.433
		48	1.5:1	**10.7**	**78.7**	**10.6**	0.544
		56	1.75:1	**13.7**	**73.6**	**12.8**	0.679
		64	2:1	**16.8**	**69.1**	**14.1**	0.826
		72	2.25:1	**20**	**65.2**	**14.8**	0.986
		80	2.5:1	**23.3**	**61.5**	**15.2**	1.160
	2 ply	40	1.25:1	**4.1**	**85.7**	**10.2**	0.417
		48	1.5:1	**5.7**	**83.2**	**11.2**	0.515
		56	1.75:1	**7.3**	**79**	**13.7**	0.633
		64	2:1	**9.1**	**75.5**	**15.4**	0.757
		72	2.25:1	**11.1**	**72.4**	**16.5**	0.887
		80	2.5:1	**13.2**	**69.6**	**17.2**	1.025
		-	-				-
2x4	1 ply	40	1.25:1	**11.7**	**78.9**	**9.4**	0.453
		48	1.5:1	**15.9**	**74.2**	**10**	0.578

		56	1.75:1	**19.9**	**68.3**	**11.8**	0.732
		64	2:1	**24**	**63.1**	**12.9**	0.905
		72	2.25:1	**28.2**	**58.5**	**13.3**	1.099
		80	2.5:1	**32.3**	**54.3**	**13.4**	1.315
	2 ply	40	1.25:1	**7**	**83.1**	**9.9**	0.430
		48	1.5:1	**9.7**	**79.6**	**10.7**	0.538
		56	1.75:1	**12.4**	**74.7**	**13**	0.669
		64	2:1	**15.3**	**70.4**	**14.3**	0.811
		72	2.25:1	**18.3**	**66.6**	**15.2**	0.965
		80	2.5:1	**21.4**	**63.1**	**15.6**	1.132

36' diaphragm width

15/32" OSB sheathing

				Percentages			
Top plate		L (ft)	Aspect ratio	**bending**	**shear**	**chord slip**	δ_{dia} (in)
2x6	1 ply	40	1.11:1	**14.6**	**69.3**	**16.2**	0.234
		48	1.33:1	**19.4**	**63.9**	**16.7**	0.305
		56	1.56:1	**23.5**	**57.1**	**19.4**	0.398
		64	1.78:1	**27.8**	**51.6**	**20.5**	0.503
		72	2:1	**32.1**	**47**	**20.9**	0.622
		80	2.22:1	**36.2**	**43**	**20.7**	0.755
	2 ply	40	1.11:1	**7.9**	**74.7**	**17.4**	0.217
		48	1.33:1	**10.7**	**70.7**	**18.5**	0.275
		56	1.56:1	**13.3**	**64.7**	**22**	0.351
		64	1.78:1	**16.2**	**60**	**23.9**	0.433
		72	2:1	**19.1**	**56**	**24.9**	0.522
		80	2.22:1	**22.1**	**52.6**	**25.3**	0.618
		-	-	**-**	**-**	**-**	-
2x4	1 ply	40	1.11:1	**21.1**	**63.9**	**14.9**	0.254
		48	1.33:1	**27.4**	**57.5**	**15.1**	0.339
		56	1.56:1	**32.6**	**50.3**	**17.1**	0.452
		64	1.78:1	**37.7**	**44.6**	**17.7**	0.583
		72	2:1	**42.6**	**39.7**	**17.7**	0.735
		80	2.22:1	**47.2**	**35.7**	**17.2**	0.911
	2 ply	40	1.11:1	**11.8**	**71.5**	**16.7**	0.227
		48	1.33:1	**15.9**	**66.7**	**17.5**	0.292
		56	1.56:1	**19.5**	**60.1**	**20.4**	0.378
		64	1.78:1	**23.2**	**54.9**	**21.8**	0.473
		72	2:1	**27.1**	**50.5**	**22.4**	0.579
		80	2.22:1	**30.9**	**46.7**	**22.5**	0.696

7/16" Plywood sheathing

				Percentages			
		L (ft)	Aspect ratio	**bending**	**shear**	**chord slip**	δ_{dia} (in)
2x6	1 ply	40	1.11:1	**7.1**	**84**	**8.9**	0.425
		48	1.33:1	**9.8**	**80.6**	**9.6**	0.531
		56	1.56:1	**12.5**	**75.8**	**11.7**	0.659
		64	1.78:1	**15.4**	**71.6**	**13**	0.798
		72	2:1	**18.5**	**67.8**	**13.7**	0.948
		80	2.22:1	**21.6**	**64.3**	**14.1**	1.111
	2 ply	40	1.11:1	**3.7**	**87.1**	**9.2**	0.410
		48	1.33:1	**5.1**	**84.8**	**10.1**	0.505
		56	1.56:1	**6.7**	**80.8**	**12.5**	0.618
		64	1.78:1	**8.4**	**77.6**	**14**	0.736
		72	2:1	**10.2**	**74.7**	**15.1**	0.860
		80	2.22:1	**12.1**	**72.1**	**15.8**	0.991
		-	-				-
2x4	1 ply	40	1.11:1	**10.7**	**80.7**	**8.6**	0.442
		48	1.33:1	**14.5**	**76.4**	**9.1**	0.561
		56	1.56:1	**18.3**	**70.7**	**10.9**	0.707
		64	1.78:1	**22.3**	**65.8**	**11.9**	0.868
		72	2:1	**26.3**	**61.3**	**12.4**	1.048
		80	2.22:1	**30.3**	**57.2**	**12.5**	1.248
	2 ply	40	1.11:1	**6.4**	**84.6**	**9**	0.422
		48	1.33:1	**8.8**	**81.5**	**9.7**	0.526
		56	1.56:1	**11.3**	**76.8**	**11.9**	0.651
		64	1.78:1	**14**	**72.8**	**13.2**	0.785
		72	2:1	**16.9**	**69.2**	**14**	0.929
		80	2.22:1	**19.8**	**65.8**	**14.4**	1.085

40' diaphragm width

15/32" OSB sheathing

				Percentages			
Top plate		L (ft)	Aspect ratio	**bending**	**shear**	**chord slip**	δ_{dia} (in)
2x6	1 ply	40	1:1	**13.5**	**71.5**	**15**	0.227
		48	1.2:1	**18.1**	**66.3**	**15.6**	0.294
		56	1.4:1	**22.1**	**59.6**	**18.2**	0.381
		64	1.6:1	**26.3**	**54.2**	**19.5**	0.479
		72	1.8:1	**30.5**	**49.7**	**19.9**	0.589
		80	2:1	**34.6**	**45.6**	**19.8**	0.712
	2 ply	40	1:1	**7.3**	**76.6**	**16.1**	0.212
		48	1.2:1	**9.9**	**72.9**	**17.2**	0.267
		56	1.4:1	**12.4**	**67.1**	**20.5**	0.339

		64	1.6:1	**15.1**	**62.4**	**22.4**	0.416
		72	1.8:1	**18**	**58.6**	**23.4**	0.499
		80	2:1	**20.9**	**55.2**	**23.9**	0.589
		-	-	-	-	-	-
2x4	1 ply	40	1:1	**19.7**	**66.3**	**13.9**	0.245
		48	1.2:1	**25.8**	**60.1**	**14.2**	0.324
		56	1.4:1	**30.9**	**52.9**	**16.2**	0.429
		64	1.6:1	**35.9**	**47.2**	**16.9**	0.551
		72	1.8:1	**40.8**	**42.3**	**16.9**	0.691
		80	2:1	**45.4**	**38.1**	**16.5**	0.852
	2 ply	40	1:1	**11**	**73.6**	**15.5**	0.221
		48	1.2:1	**14.8**	**69**	**16.3**	0.283
		56	1.4:1	**18.3**	**62.6**	**19.1**	0.363
		64	1.6:1	**21.9**	**57.5**	**20.6**	0.452
		72	1.8:1	**25.6**	**53.1**	**21.2**	0.550
		80	2:1	**29.3**	**49.3**	**21.4**	0.659

7/16" Plywood sheathing

			Aspect ratio	**Percentages**			δ_{dia} (in)
		L (ft)		**bending**	**shear**	**chord slip**	
2x6	1 ply	40	1:1	**6.5**	**85.4**	**8.2**	0.418
		48	1.2:1	**9**	**82.2**	**8.8**	0.521
		56	1.4:1	**11.5**	**77.7**	**10.8**	0.643
		64	1.6:1	**14.3**	**73.7**	**12**	0.775
		72	1.8:1	**17.2**	**70.1**	**12.7**	0.917
		80	2:1	**20.2**	**66.7**	**13.1**	1.071
	2 ply	40	1:1	**3.3**	**88.2**	**8.4**	0.418
		48	1.2:1	**4.7**	**86.1**	**9.2**	0.521
		56	1.4:1	**6.1**	**82.4**	**11.4**	0.643
		64	1.6:1	**7.7**	**79.4**	**13**	0.775
		72	1.8:1	**9.4**	**76.7**	**13.9**	0.917
		80	2:1	**11.2**	**74.1**	**14.6**	1.071
		-	-				-
2x4	1 ply	40	1:1	**9.8**	**82.3**	**7.9**	0.434
		48	1.2:1	**13.4**	**78.2**	**8.4**	0.548
		56	1.4:1	**17**	**72.9**	**10.1**	0.686
		64	1.6:1	**20.8**	**68.1**	**11.1**	0.839
		72	1.8:1	**24.6**	**63.8**	**11.6**	1.007
		80	2:1	**28.5**	**59.8**	**11.8**	1.195
	2 ply	40	1:1	**5.8**	**86**	**8.2**	0.415
		48	1.2:1	**8.1**	**83**	**8.9**	0.516
		56	1.4:1	**10.4**	**78.6**	**10.9**	0.636
		64	1.6:1	**13**	**74.8**	**12.2**	0.763
		72	1.8:1	**15.7**	**71.4**	**13**	0.900
		80	2:1	**18.4**	**68.1**	**13.4**	1.048

Min %	3.3	23.5	7.9
Max %	56	88.2	33.1
Avg %	21.4	60.7	17.9