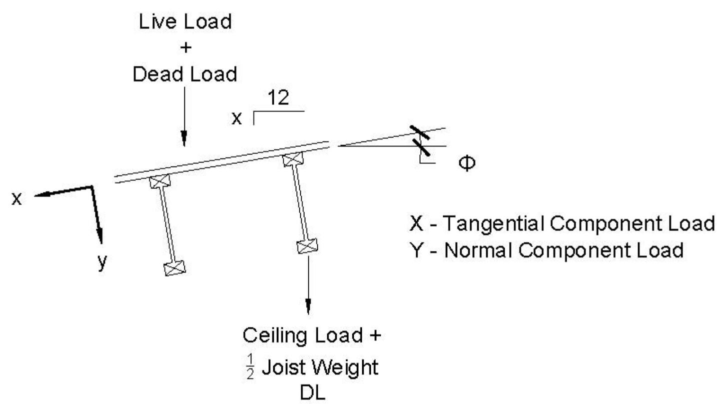
Technical Support
888-453-8358
TechSupport@Wy.com

TJI® Joists Installed Out of Plumb

Trus Joist® TJI® joists have been engineered for use in vertical orientations. Other methods of installation, such as 'out of plumb' (e.g. purlin) applications introduce inherent complications into the design and detailing of the roof system that will require further consideration during the project design stage by the design professional responsible for the project. Trus Joist Microllam® LVL, Parallam® PSL, or TimberStrand® LSL with rectangular cross-sections have higher bending capacity in a rotated axis and are better suited for this application.

In cases where a TJI® joist is used as an out-of-plumb roof purlin, the following design considerations must be addressed by the Designer of Record (DOR):

- Design the TJI® joist for the normal (Y) component load.
- Design the sheathing to resist the tangential (X) component load. This load is in addition to the lateral (wind and seismic) load being transferred into the roof diaphragm.
- Restrain the joist's bottom flange from any loads suspended from the bottom chord.
- Check the "bi-axial bending" of the bottom flange. Restrain if needed.
- If the TJI® purlin is bottom bearing, design connections and blocking at bearing to transfer lateral loads.
- If the TJI® purlin is supported by a hanger, contact hanger manufacturer for design assistance.
- Resolve forces induced by joist blocking used to prevent purlin rotation into wall below at low end of roof.
- Provide guidelines for a safe and stable installation.



DESIGN CONSIDERATIONS

Normal and Tangential Loads

Unlike a roof rafter where the structural member is installed parallel to the roof slope, purlins can be oriented perpendicular to the slope. When TJI® joists are installed in this orientation, the applied load is split into two components, normal and tangential, which are resisted by different elements in the roof system. The normal component load is the portion of vertical load that will be transferred through the TJI® joist along the rotated Y-axis. The tangential component is the load that will be resisted by the roof sheathing along the X-axis. Both the TJI® joist and the roof sheathing must be properly designed to support these loads.

Blocking Requirements

Blocking between TJI® joists will keep the flanges aligned and provide buckling resistance. Blocking will be required when the calculated unbraced length (l_u) of the bottom flange is *less than or equal to* the joist clear span. The unbraced length is also dependent upon the joist's allowable lateral deflection, the stiffness of the flange in the Y-axis, and the load imposed on the bottom flange (typically the suspended ceiling load, other suspended loads, and ½ the weight of the joist). The blocking on-center spacing must be less than or equal to the maximum unbraced length.

TJI® (Out of Plumb) Bi-axial Bending

The design moment of a TJI® joist about the X-axis is first calculated to evaluate its capacity under normal component loads. When the joist is rotated out of plumb, moment is also generated about the Y-axis, which puts the member in "bi-axial bending". The joist's design-to-control moment ratio about the X-axis plus the design-to-control moment ratio about the Y-axis must be less than 1.

An out of plumb TJI® joist with structural sheathing is considered supported along the top flange, therefore only the bottom flange needs to be checked for bi-axial bending. If structural sheathing is not applied to the top flange (e.g. metal roofs), the full depth of the joist must be checked for "bi-axial bending". This is a complex analysis and is not recommended.

Ceiling type is also a factor for this check. If the load on the bottom flange is small, the project Designer of Record, may determine a directly applied ceiling is sufficient to restrain the flange between the blocking panels. When using a suspended ceiling, the bottom flange between the blocking must be checked for bending along both axes and restrained against lateral deflection as required.

Additional considerations may be necessary to ensure safe installation. Long spans or high slope conditions may require more blocking than indicated per the bi-axial bending analysis to ensure the roof joists are installed and maintained in a straight orientation (blocking is installed to prevent lateral deflection), to provide sufficient spacing from joist flange edge when attaching roof sheathing. It is the responsibility of the DOR to determine acceptable lateral deflection during framing, and any supplementary blocking requirements to meet such criteria.

End Bearing Restraint
The out of plumb TJI® joist must be restrained at end bearing to prevent roll-over and/or sliding of the roof system off the bearing. As the roof pitch increases, the tangential PLF load along the end bearing also increases. Blocking is required to help transfer that load from the sheathing to the support below.

Other Design Considerations
Finally, the following items should be considered when planning for the installation of rotated TJI® joists:

- For barrel vaults, look at the worst case out of plumb TJI® joist, which is normally the first one.
  - Each blocking panel will have a custom angle. Precision analysis and installation in this scenario is time consuming and difficult. If TJI® joists require mid-span blocking, a solid section joist may be a better solution for barrel vault applications.
- Begin placing members at the low end of the roof and install the blocking as the subsequent joists are installed.
- TJI® flanges must align in a plane perpendicular to the roof deck to within ¼" to allow proper sheathing attachment (see section 5 of the design example).
- Hangers must be verified with the hanger manufacturer for acceptability in purlin orientation and load capacity. Hanger capacity reductions and reinforcement requirements may apply.
- Ventilation can be more difficult in this application.
  - Holes will need to be cut into the TJI® joist web if ventilation is to be provided in the ceiling cavity. Refer to TJI® joist allowable holes chart in TJ-4000 for location and size.
  - If ventilation is required at roof sheathing, holes must be placed in the web. Notching the flanges is not permitted.
  - Air flow volume may differ when using holes in the joist web instead of the typical air gap between top of insulation and roof sheathing.

For a more detailed analysis, see attached design example beginning on page 3.

TJI® JOIST OUT OF PLUMB DESIGN CHECK

This bi-axial bending design example is based on principles discussed in the Wood Engineering and Construction Handbook, Third Edition (1998).

Roof Diaphragm Loads

1) Determine the normal (perpendicular) load on the Trus Joist® TJI® joists using the roof pitch and the loading.

$Y_{LL} = W_{LL}\cos(\theta)$
$Y_{DL} = W_{DL}cos(\theta)$

Where:

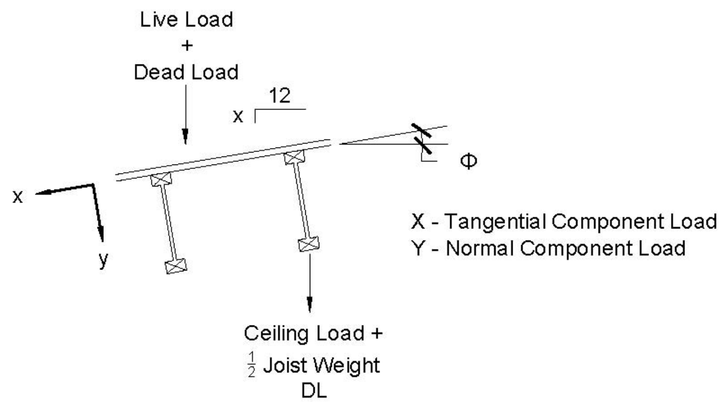
ϕ = Angle of the roof = $\tan^{-1}$ (pitch)

W_{LL} = Live load on roof (psf)

W_{DL} = Dead load on roof (psf)

Y_{LL} = Normal live load applied to TJI joist

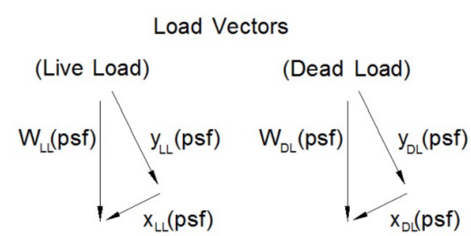
Y_{DL} = Normal dead load applied to TJI joist



2) Design the TJI® roof joists with the normal load from step one. Forte®WEB single member sizing software can be found at http://www.weyerhaeuser.com/woodproducts/software-learning/forte-software/.

3) Determine tangential forces to be applied to sheathing in the x-direction. (Sheathing check is outside the scope of this informer)

$X_{LL} = W_{LL}\sin(\theta)$
$X_{DL} = W_{DL}\sin(\theta)$



Where:

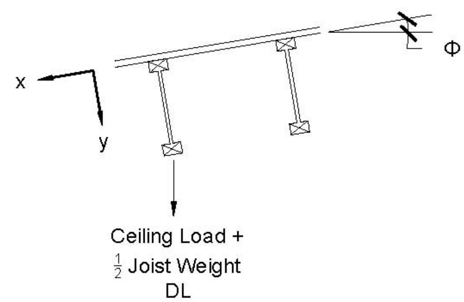
X_{LL} = Live Load supported by sheathing (psf)

X_{DL} = Dead Load supported by sheathing (psf)

Bracing the Bottom Flange

4) Determine the load perpendicular to the bottom flange using half of the weight of the TJI® joist plus the ceiling weight. (e.g. gypsum, mech'l, etc).

$$w_{BL} = \left(\frac{(W_{CL} \cdot o.c.spacing)}{\frac{12\ in}{ft}} + \frac{w_{JL}}{2} \right) \sin(\theta)$$



Where:

w_{BL} = load on bottom chord (plf)

W_{CL} = dead load of ceiling (psf)

w_{JL} = weight of joist (plf), refer to TJ-4000 specifier guide

5) Determine the allowable lateral deflection of the flange in the x-direction.

$$\Delta_{Horz} = d\left(\frac{1ft}{12in}\right)\left(\frac{{}^{1}/_{4}\,in}{1ft\ depth}\right)$$

Where:
$\Delta_{Horz.}$ = Allowable lateral deflection of bottom flange (in) [Maximum recommended is ¼" per foot of depth of joist]
d = joist depth in inches

6) Determine the allowable unbraced length of the bottom flange for out-of-plane flange buckling.

$$l_u = \left(\frac{384 \cdot EI_{YY} \cdot \Delta_{Horz}}{\frac{5 \cdot W_{BL} \cdot (1\ ft)}{12\ in}}\right)^{1/4}$$

Where:
l_u = Unbraced length (in)
E = Microllam LVL flange modulus of elasticity per ESR-1387 (psi), use lowest published MOE for worst case (see example)
I_{YY} = Flange moment of inertia y-y axis(in^4) $\left[I = \frac{db^3}{12} - I_{WR}\right]$
d (flange depth) = Use 1.25" for TJI 110, 210, & 230 joists
- Use 1.375" for TJI 360, 560, & 560D joists

b (flange width) = based on series (Flange geometry can be found in ESR-1153 or TJ-4000)
I_{WR} = moment of inertia of flange web rout
- Ignore due limited effect of flange rout to moment of inertia calculation (use value of 0)

w_{BL} = weight on bottom chord (plf), per step 4

- Place blocking within the joist span such that blocking spacing does not exceed l_u.
- Full depth blocking shall be used for lateral bracing of the joist length.
- Recommend connecting blocking per PB1 detail found in TJ-4000 TJI specifier guide.
- Cumulative blocking load must be resolved into the roof diaphragm or at the low end of roof per project DOR.

7) Verify unbraced length deflection meets minimum roof criteria: $l_{u\Delta\ criteria} \geq 180$

$$l_{u\ \Delta criteria} = \frac{l_{blocked}\ (in)}{\Delta_{Horz}(in)} \geq 180$$

8) Check the combined stresses in the bottom flange. Set blocking at equal intervals over joist span.

$$M_{YY\ Blked} = \varphi W_{BL} \left(\frac{L}{n}\right)^2$$

$$M_{YY\ All} = F'_{bYY} S$$

Where:

$M_{YY\ Blked}$ = Design flange moment if blocked at even spacing
L = Joist clear span between supports (ft)
n = Number of blocked joist bays, rounded up to nearest whole number → $n = \frac{L}{l_u}$
l_u = Maximum unbraced lateral joist span, converted to ft
φ = Moment factor (moment coefficient for uniformly loaded multiple spans)

- φ = 0.125 for 1 bracing row (2 spans)
- φ = 0.100 for 2 bracing rows (3 spans)
- φ = 0.107 for 3 bracing rows (4 or more spans)

F'_{bYY} = Allowable bending stress in bottom flange (psi) $[F'_{bYY} = f_{bYY} C_d C_M C_t C_L C_V C_r]$

- f_{bYY} = Beam orientation bending stress of flange material (psi) (lowest grade Microllam® LVL = 2140 psi)
- C_D = Load duration factor (use 0.9 if dead load only)
- C_M = Wet service factor (use 1.0, TJI Joist are intended for dry-use applications only)
- C_t = Temperature factor
- C_L = Beam stability factor (use 1.0 due to bi-axial bending limiting compression in joist bottom flange, additional analysis may need to be considered for wind uplift conditions)
- C_V = Volume factor → 1.18 per ESR-1387
- C_r = Repetitive member factor (use 1.0)

S = Section modulus about YY (in^3) $\left[S = \frac{db^2}{6} - S_{WR}\right]$

- b = flange width (found in TJ-4000 & ESR-1153)
- d (flange depth) = Use 1.25" for TJI 110, 210, & 230 joists
- \- Use 1.375" for TJI 360, 560, & 560D joists
- S_{WR} = Section modulus of web rout
  - Ignore due limited effect of flange rout to section modulus calculation (use value of 0)

Interaction Equation

$$\left(\frac{M_{XX}}{M_{X\ Allow}}\right) + \left(\frac{M_{YY\ Blked}}{M_{Y\ All}}\right) \leq 1.0$$

- M_{XX} = Design Moment from step 2
- $M_{X\ Allow}$ = Allowable Moment from step 2
- $M_{YY\ Blked}$ = Lateral Moment resisted by bottom flange
- $M_{Y\ All}$ = Allowed Lateral Moment of bottom flange

TJI® JOIST OUT OF PLUMB DESIGN EXAMPLE

Given:

14" TJI 110's at 24" o.c.
15' span
6/12 roof pitch
Snow load = 25 psf (1.15 LDF)
Dead load = 16 psf (0.90 LDF)
TJI® flange dimension: 1-1/4" x 1-3/4"

2.5 psf	Asphalt shingles
2.7 psf	48/24 T&G
1.2 psf	R30 insulation
1.4 psf	14" TJI 110 @ 24" o.c. (2.8 lb/ft)
5.6 psf	(2) layers of 5/8" gypsum
2.0 psf	2" dia. water filled pipe
15.4 psf	Total (round to 16 psf)

Roof Diaphragm Loads

1) Determine the normal (perpendicular to sheathing) load.

$$\theta = \tan^{-1}\left(\frac{6}{12}\right) = 26.57°$$

$$Y_{SL} = 25\ psf \cdot \cos(26.57°) = 22.36\ psf$$

$$Y_{DL} = 16\ psf \cdot \cos(26.57°) = 14.31\ psf$$

2) Design the TJI® joist in Forte®WEB with the normal component of load. (Remember, the member in this calc will have 0/12 slope. See example Forte®WEB calculation included on page 9)

Design Results:

$M_{XX} = 1931$ *ft-lbs*

$M_{X\ Allow} = 4301$ *ft-lbs*

$V_{XX} = 523$ *lbs*

3) Determine tangential forces to be applied to sheathing in the y-direction. (Designer of Record to confirm adequacy of diaphragm).

$$X_{LL} = 25\ psf_{SL} \cdot \sin(26.57°) = 11.18\ psf$$

$$X_{DL} = 16\ psf_{DL} \cdot \sin(26.57°) = 7.16\ psf$$

Bracing the Bottom Flange

4) Determine the load perpendicular to the bottom flange: $W_{BL} = \left((W_{CL} \cdot o.c.spacing) + \frac{w_{JL}}{2}\right)\sin(\theta)$

w_{BL} = weight on bottom chord (plf)
W_{CL} = dead weight of dropped ceiling (psf)
w_{JL} = weight of joist (plf)

$$W_{CL} = 5.6\ psf_{gypsum} + 2.0\ psf_{water\ pipe} + 1.2psf_{R30\ insulation} = 8.8\ psf$$

Therefore, weight on bottom chord is:

$$w_{BL} = \left[(8.8\,psf \cdot 2ft\;o.c.) + \left(\frac{2.8\,plf}{2}\right)\right]\sin(26.56°) = 8.50\,plf$$

5) Determine the allowable lateral deflection of the bottom flange.

$\Delta_{Horz} = 14in\left(\frac{1\,ft}{12\,in}\right)\left(\frac{0.25\,in}{1\,ft\,depth}\right) = 0.29\,in$ (*DOR to determine if this is an acceptable limitation for the application*)

6) Determine the spacing of the bottom flange bracing.

$$I_{YY} = \left(\frac{1.25in(1.75in)^3}{12} - 1.17 \cdot 10^{-3} in^4\right) = 0.55\,in^4$$

$$l_u = \left(\frac{384 E I_{YY} \Delta_{Horz}}{5W_{BL}\left({}^{1ft}/_{12in}\right)}\right)^{1/4}$$

$$l_u = \left(\frac{384 \cdot (1.6 \cdot 10^6\,psi)(0.55\,in^4)(0.29in)}{5 \cdot (8.50\,plf)\left({}^{1ft}/_{12in}\right)}\right)^{1/4} \rightarrow 72.5\,in\;or\;6.1\,ft$$

- E = 1.6 x 10^6 psi (use 1.6E, assume the lowest published MOE for Microllam® LVL per ICC-ES ESR-1387 as flange material)

$$\frac{L}{l_u} = \frac{15ft_{out\;to\;out}}{6.1\,ft} \rightarrow 2.47\;(round\;up\;to\;3) \rightarrow Requires\;3\;blocked\;sections\;of\;joist\;span$$

- Block joist at 5ft on center (3 blocked sections – 1 = 2 required rows of blocking).
- $l_{blocked} = 5ft$

7) Verify rotated flange unbraced length deflection meets minimum roof criteria: $l_{u\,\Delta\,criteria} \geq 180$

$$l_{u\,\Delta criteria} = \frac{5\,ft\left(\frac{12in}{1ft}\right)}{0.29\,in} \rightarrow 206.9 \geq 180\;therefore\;OK$$

8) Check the combined stresses on the TJI® flange.

$$M_{YY\ Blked} = \varphi W_{BL}\left(\frac{L}{n}\right)^2$$

$$M_{YY\ Blked} = 0.100(7.42\ plf)\left(\frac{15ft}{3\ bays}\right)^2\left(\frac{12in}{ft}\right) \rightarrow \mathbf{222.6\ in - lbs}, Lateral\ Bending\ Moment\ When\ Blocked\ at\ 5ft\ o.c.$$

$$F'_{bYY} = f_{bYY}C_dC_MC_tC_LC_VC_r$$
$$M_{YY\ Allow} = F'_{bYY}S$$

$$F'_{bYY} = 2140\ psi(0.90)(1.18) \rightarrow 2273\ psi$$

$$M_{YY\ Allow} = 2273\ psi\left(\frac{1.25in \cdot (1.75in)^2}{6} - 4.67 \cdot 10^{-3}in^3\right) \rightarrow 1439\ in - lbs$$

From Step 2

M_{xx}= 1951 ft-lbs $M_{X\ Allow}$= 4301 ft-lbs

Interaction Equation

$$\left(\frac{1951\ ft - lbs}{4301\ ft - lbs}\right) + \left(\frac{222.6\ in - lbs}{1439\ in - lbs}\right) \rightarrow 0.61 \leq 1\ \boldsymbol{OK}$$

- O.K. with 2 rows of full depth blocking.

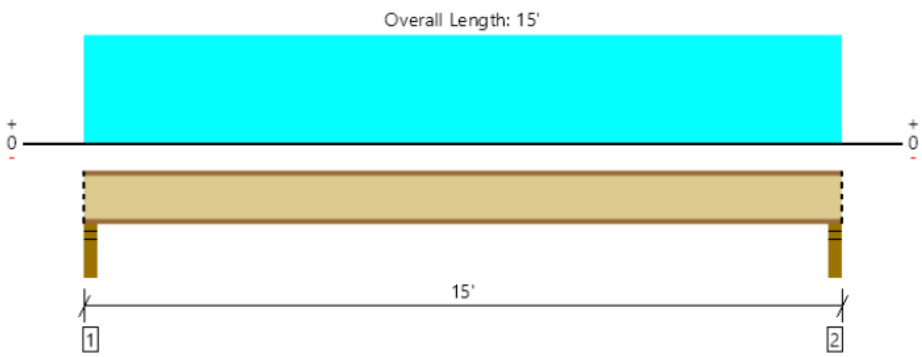
Reminder: TJI® joists rotated out of plumb must be restrained at the ends with full depth blocking. If the end bearing condition is flush, consult the hanger manufacturer for hanger capacity reduction and reinforcement requirements.

FORTE® WEB

MEMBER REPORT

PASSED

Rotated Roof Framing, Out of Plume Roof Joist
1 piece(s) 14" TJI® 110 @ 24" OC



All locations are measured from the outside face of left support (or left cantilever end). All dimensions are horizontal.

Design Results	Actual @ Location	Allowed	Result	LDF	Load: Combination (Pattern)
Member Reaction (lbs)	551 @ 2 1/2"	1581 (3.50")	Passed (35%)	1.15	1.0 D + 1.0 S (All Spans)
Shear (lbs)	529 @ 3 1/2"	2139	Passed (25%)	1.15	1.0 D + 1.0 S (All Spans)
Moment (Ft-lbs)	1951 @ 7' 6"	4301	Passed (45%)	1.15	1.0 D + 1.0 S (All Spans)
Live Load Defl. (in)	0.134 @ 7' 6"	0.486	Passed (L/999+)	--	1.0 D + 1.0 S (All Spans)
Total Load Defl. (in)	0.220 @ 7' 6"	0.729	Passed (L/794)	--	1.0 D + 1.0 S (All Spans)

- Deflection criteria: LL (L/360) and TL (L/240).
- Allowed moment does not reflect the adjustment for the beam stability factor.

System : Roof
Member Type : Joist
Building Use : Residential
Building Code : IBC 2015
Design Methodology : ASD
Member Pitch : 0/12

Supports	Bearing Length			Loads to Supports (lbs)				Accessories
	Total	Available	Required	Dead	Roof Live	Snow	Total	
1 - Stud wall - SPF	3.50"	3.50"	1.75"	215	269	336	820	Blocking
2 - Stud wall - SPF	3.50"	3.50"	1.75"	215	269	336	820	Blocking

- Blocking Panels are assumed to carry no loads applied directly above them and the full load is applied to the member being designed.

Lateral Bracing	Bracing Intervals	Comments
Top Edge (Lu)	4' 6" o/c	
Bottom Edge (Lu)	15' o/c	

- TJI joists are only analyzed using Maximum Allowable bracing solutions.
- Maximum allowable bracing intervals based on applied load.

Verify bottom edge bracing, indicated to the left, is not exceeded per out of plumb analysis.

Vertical Load	Location (Side)	Spacing	Dead (0.90)	Roof Live (non-snow: 1.25)	Snow (1.15)	Comments
1 - Uniform (PSF)	0 to 15'	24"	14.3	17.9	22.4	Normal Force on Rotated TJI Joist

Weyerhaeuser Notes

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The product application, input design loads, dimensions and support information have been provided by Mason county