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Connection Design Methodology for Structural Composite Lumber

by

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Abstract

NDS-97 contains allowable design values for connections based on their application to various species and species groups of solid-sawn lumber only. For purposes of connection design, these species are grouped by their specific gravity (SG). Effective SG values are assigned to SCL for various fastener types in various configurations through the method of Equivalent Specific Gravity (ESG). Several examples demonstrate the derivation and use of ESG values for SCL. ESG values for a selection of SCL products are also tabulated.

Introduction

Structural Composite Lumber (SCL) defines a class of engineered wood products made from adhering veneer sheets or wooden strips together with exterior structural adhesives (Smulski, 1997). By "reconstituting" raw lumber in this fashion, physical defects such as slope of grain and knots are effectively redistributed. This results in a lumber-like material with far more homogeneous structural characteristics that makes far more efficient use of the raw material then does solid-sawn lumber. For these primary reasons, SCL has become increasingly apparent in the wood framing industry since its commercial development in the 1960's. The issue of connection design for SCL using the 1997 National Design Specification for Wood Construction (NDS-97) is addressed in this paper.

Procedure for Determining Equivalent Specific Gravity

ASTM (1998a) Standard D5456-98a Annex A2 outlines the procedures for determining ESG of SCL. The procedure basically uses existing NDS-97 tables of allowable values for various connection types in solid-sawn wood and "back calculates" to find an ESG correlating to a test value determined in a SCL product. Three cases are examined by the standard: withdrawal of nails and wood screws, dowel bearing strength (DBS) for nails and wood screws, and dowel bearing strength for bolts and lag screws. In addition to determining ESG values for various connector applications, ESG values can be further defined based on fastened orientation. That is, whether the fastener is oriented in the X-direction (parallel to the glue surface for veneer type composites) or the Y-direction (normal to the glue surface of veneer type composites) as defined by Figure 1. Theoretically, it is possible to derive six ESG values for any piece of SCL material depending on fastener type, application and orientation. For some SCL products examined for this paper, the published information did not include all six ESG values for multiple connection types, applications and orientations. It should be noted that the ASTM procedures reviewed herein do not apply to connections outside the domain of nails, wood and lag screws, and bolts (such as shear plate connectors, and timber rivets.)

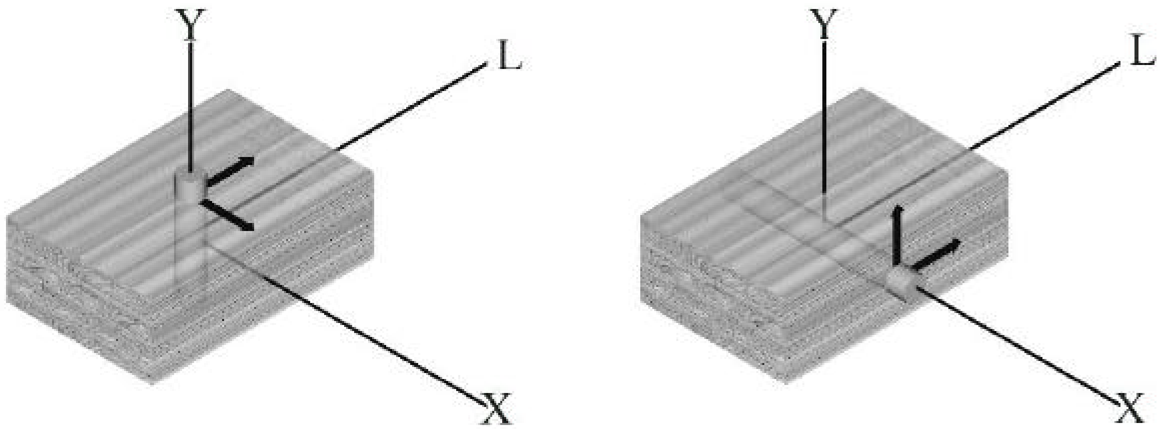

Figure 1. **Fastener orientation versus glue line orientation is depicted. The left image shows a fastener in the "Y" orientation. The image on the right shows a fastener in the "X" orientation. Though SCL does not have "grain" in the conventional sense that solid-sawn lumber does, when a fastener oriented along the X or Y-axis is loaded in the L direction, it is likened to loading parallel-to-grain in solid-sawn lumber. When the same fastener is loaded in the Y or X direction respectively, it is likened to loading perpendicular-to-grain in solid-sawn lumber.**

Withdrawal Strength

ASTM (1998a) Standard D5456-98a Annex A2 defines the following procedure for finding ESG values in the X and Y orientations for nail and screw withdrawal applications. (Annex A2 does not address nails and screws in the L orientation, or end-grain.) Testing procedure references ASTM (1998) D1761-88. This standard establishes the protocol for determining withdrawal capacity in solid-sawn lumber. The test setup uses a minimum 8d common wire nail imbedded at least 1.25 inches. Average withdrawal strengths per inch of penetration for the X and Y orientations are determined. Each value is divided by a safety factor of 5.0. The reduced value is then used to enter Table 12.2A of NDS-97 (American Forest & Paper Association, 1997). A tabulated SG value not greater than that of the test value is selected for defining the withdrawal strength of the fastener. The selected SG becomes the ESG value for that particular orientation of the fastener. Straight-line interpolation between strengths is permissible to attain a more accurate ESG. Once attained, the ESG for the X or Y orientation of the fastener applies in withdrawal of any nail or wood screw type or size in the same respective orientation. If only one ESG is to be specified for all fastener orientations, it must be the lowest of all values for the X and Y orientations.

<u>Example 1: Withdrawal Test Values and ESG</u>

In the following example, ESG was determined for the load case of withdrawal in the X and Y fastener orientation. In the example, ESG was based on the withdrawal capacities for 8d common wire nails, 0.131 inches in diameter, and with 2.0 inches of penetration. Average withdrawal capacities of 160 and 200 lb/inch penetration were determined for the X and Y nail orientations respectively. Dividing by the 5.0 safety factor yielded an allowable withdrawal capacity of 32 and 40 lb/inch penetration for the respective fastener orientations. By entering Table 12.2A in NDS-97, ESG values of 0.50 and 0.54 are determined to correspond to allowable withdrawal capacity for the X and Y orientation. The results are summarized in Table 1.

Table 1. Example test data on a Common nail in withdrawal and the derived ESG values needed for design purposes.

Nail type	8d Common
Length	2.5 Inches
Diameter	0.131 Inches
Penetration depth	2.0 Inches

Nail Orientation (See Figure 1)	X-axis	Y-axis
Average Withdrawal Load (lb)	320	400
Strength per Inch of Penetration (lb/in)	160	200
Allowable (Divide by 5.0)	32	40
ESG (Table 12.2A NDS-97)	**0.50**	**0.54**
ESG for X or Y-axis orientation	**0.50**[a]	

[a] For application to both X and Y orientations, select the lower ESG of 0.5.

Lateral Resistance: Dowel Bearing Strength (Nails and Screws)

ASTM (1998b) test procedure D5764-97a (dowel bearing test) is the appropriate procedure to determine lateral resistance values for nails and wood screws in the X and Y orientations. D5764-97a calls for testing using a minimum 10d common wire nail. The nail is loaded in both directions normal to its shank axis. That is, for a nail with X-axis orientation, this implies loading in the Y and L directions. For a nail with Y-axis orientation, this implies loading in X and L directions. As in the case of withdrawal, ESG is determined separately for each fastener orientation. Lateral design values for nails and screws in the L orientation (end grain) are generally not available in the SCL product literature.

For each orientation, the $P_{5\%offset}$ method is used to attain values of lateral load in each of the two loading directions. The $P_{5\%offset}$ value is either the peak load or the intersection of a parallel line offset 5% of the nail diameter from the origin of the load-deflection curve, whichever occurs first. Dowel bearing strength (DBS) for each loading direction is then determined by dividing the $P_{5\%offset}$ value by the nail diameter and specimen thickness. The offset DBS value for each loading direction is then averaged. If this average test value differs by less then 20% of the DBS for each loading direction, then it is used to enter Table 12A of NDS-97. Here, a SG having DBS not more than that of the average test value is assigned as the ESG for the respective orientation. If DBS for each loading direction differs by more than 20% from the average, then the smaller DBS value is divided by 0.80 and used to enter Table 12A of NDS-97. Since the F_e values in Table 12A are rounded to the nearest 50 psi, the formula in the footnote relating specific gravity (G) to F_e can be rewritten to attain a more accurate ESG value:

$$ESG = \left(\frac{F_e}{16600} \right)^{0.5435} \quad (1)$$

where: F_e = Dowel bearing strength, psi.

Once attained, values of ESG for fasteners installed in the X or Y orientation apply to lateral loading of any nail or wood screw type or size in the like orientation. If one ESG is to be specified for all fastener orientations, it must be the lowest of all values for the X and Y orientations.

<u>Example 2: DBS (Nails and Screws) and ESG</u>

In this example, a laterally loaded 10d common wire nail fastener is used to determine ESG of a SCL. Following ASTM (1998a,1998b) test procedures D5456-98a and D5764-97a, a DBS of 4000 and 6800 psi is determined for a fastener oriented along the X-axis, and loaded in the Y and L directions, respectively, as shown in Figure 1. Referring to the test data in Table 2, since the average for the two load directions (5400 psi) exceeds the smaller value (4000) for the Y-loading direction by more than 20%, the smaller value is divided by 0.8 to yield a DBS of 5000 psi used to enter NDS-97 Table 12A. Using Equation 1, an ESG of 0.52 is determined to be appropriate for these fasteners oriented along the X-axis. This procedure is repeated for the fasteners oriented along the Y-axis. DBS of 5800 and 7600 psi are determined for loading in the X and L directions, respectively. However, in this case, the DBS for loading in the X and L directions differs by less then 20 percent. Therefore, the average DBS value of 6700 psi is used to enter Table 12A. Here an ESG of 0.61 is determined to be appropriate for Y-axis oriented fasteners. The results are summarized in Table 2.

Table 2. Example test data on a Common nail laterally loaded in SCL. The last two lines give the ESG needed for design using the NDS.

Nail type	10d	Common
Length	3.0	inches
Diameter	0.148	inches

Nail Orientation (See Figure 1)	X-axis		Y-axis	
Loading Direction	Y	L	X	L
DBS[a] (psi)	4000	6800	5800	7600
Average	5400		6700	
% difference	26[b]		13[c]	
DBS value used to enter Table 12A	5000		6700	
ESG from Table 12A	**0.52**		**0.61**	
ESG for X or Y-axis orientation	**0.52[d]**			

[a] $P_{5\%off}$ value / (nail diameter * specimen thickness)
[b] For the X orientation, the percent difference is greater than 20. The smaller DBS value for loading in the Y direction is divided by 0.8 and used to enter Table 12A. (4000 / 0.8 = 5000)
[c] For the Y orientation, the percent difference is less than 20. The average DBS value is used to enter Table 12A.
[d] For application to both X and Y orientations, select lower ESG.

Dowel Bearing Strength (Bolts and Lag Screws)

Determining the DBS for bolts and lag screws in the X and Y orientation again makes use of ASTM (1998b) test procedure D5764-97a. The test setup is similar to that for nails and screws except that DBS values are determined for both ½ inch and ¾" bolts. The $P_{5\%offset}$ value is attained for each loading case and each bolt type. The $P_{5\%offset}$ values are divided by the bolt diameter and the specimen thickness to determine a DBS for each bolt size and loading direction. DBS for fastener loading in the L direction is called "$F_{e||}$". It is used in Table 8A of NDS-97 to find an ESG having a $F_{e||}$ not higher than the test value. The DBS for loading of the fastener in the X or Y directions is called "$F_{e\perp}$". It is used in Table 8A of NDS-97 to find an ESG having a $F_{e\perp}$ value not higher than the test value. These ESG values apply to their respective bolt size and loading direction. Since tabulated values in NDS-97 Table 8A were rounded to the nearest 50 psi, Equations 2 and 3 were derived from the Footnote 2 to attain more accurate values of ESG, given $F_{e||}$ and $F_{e\perp}$:

$$ESG_{||} = \frac{F_{e||}}{11200} \tag{2}$$

$$ESG_{\perp} = \left(\frac{F_{e\perp} * \sqrt{D}}{6100} \right)^{0.6897} \tag{3}$$

where: $F_{e||}$ = Dowel bearing strength parallel-to-grain, psi (L direction),

$F_{e\perp}$ = Dowel bearing strength perpendicular-to-grain, psi (X or Y direction),

and

D = Dowel (bolt) diameter, inches.

For a given bolt orientation, four ESG values can be calculated from the test results on two bolt sizes and two loading directions. The average of the four values is calculated. If no value differs from the average by more than 0.03, then the average value becomes the ESG for that bolt orientation. If any value differs by more than 0.03 from the average, then the lowest value plus 0.03 is used to attain the ESG for that bolt orientation. Once an ESG is attained for the X and Y bolt orientations depicted by Figure 1, it can be applied for any laterally loaded bolt and lag screw connections in the same orientation. If one ESG is to be specified for any fastener orientation, it must be the lower value of the X or Y orientations.

Example 3: DBS (Bolts and Lag Screws) and ESG

In Example 3, sample DBS values have been obtained for ½ and ¾ inch bolts. The values are classified first on the basis of the bolt orientation (X or Y) and then on the basis of loading direction. Bolts installed in the X-axis orientation can be loaded in the Y or L directions. Bolts installed in the Y-orientation can be loaded in the X or L direction (See Figure 1). Next the ESG values are determined for each bolt size, loading direction and fastener orientation. For a given fastener orientation, the values have been averaged. Then, on the basis of footnotes b and c, the ESG each fastener orientation (X or Y) is identified. Table 3 summarizes the process.

Table 3. **Example test data on a bolted connection. Eight DBS tests can be reduced to two design values for ESG, or the lowest value can be used for all bolt orientations.**

Bolt Orientation			X-axis		Y-axis	
Loading Direction			Y (⊥-to-grain)	L (‖-to-grain)	X (⊥-to-grain)	L (‖-to-grain)
	1/2 inch Bolt					
		DBS[a] (psi)	2900	6350	3850	6850
		ESG	0.472	0.567	0.573	0.612
	3/4 inch Bolt					
		DBS (psi)	2550	6600	3350	7050
		ESG	0.496	0.589	0.599	0.629
Avg. ESG for all bolts and loading directions			0.531		0.603	
ESG specified			**0.50**[b]		**0.60**[c]	
ESG for X or Y-axis orientation			**0.50**[d]			

[a] $P_{5\%off}$ value / (nail diameter * specimen thickness)
[b] For the X orientation, ESG for each bolt and load direction is not within 0.03 of the average. The smallest ESG value plus 0.03 is therefore specified. (0.472 + 0.03 = 0.50)
[c] For the Y orientation, ESG for each bolt and load direction is within 0.03 of the average. The average ESG value is therefore specified.
[d] For application to both X and Y orientations, select lower ESG.

Product Information

The following section considers briefly, three types of SCL. A description of each product is given along with manufacturer's ESG values. Several design examples illustrate the application of these values.

<u>Laminated Strand Lumber</u>

Laminated Strand Lumber (LSL) is a SCL product manufactured with species (Yellow Poplar or Aspen, for example) that may not otherwise be viable as solid-sawn lumber for structural applications requiring high strength. These species are shredded into strands up to 12 inches in length. The strands are then realigned in parallel order. This procedure effectively distributes flaws or defects in the wood and provides for the most effective use of fiber strength. The strands are bonded together in large billets (5½" X 8' X 48') using adhesives. The final product can then be cut from these billets in a variety of depths, widths and lengths. The most common application of LSL, however, is of header and rimboard applications. It can also be sawn into "2X4" material for wall framing applications.

Manufacturer's literature (as of April 1999) indicated the following ESG values for the associated products:

Manufacturer & Product	**Load Case**	**ESG**	
		Fastener Orientation	
		X-axis	Y-axis
TrusJoist MacMillan *TimberStrand®*	Withdrawal	0.42	0.42
	DBS (nails & wood screws)	0.50	0.50
	DBS (bolts & lag screws)	-	0.58

Note: Designers should obtain updated data from the manufacturer.

Laminated Veneer Lumber

Laminated veneer lumber (LVL) is a general term used to describe a product made by sandwiching thin veneers of wood in a parallel grain orientation. This differs from plywood where the veneers are criss-crossed with opposing grain orientations. LVL improves on conventional sawn lumber in that it makes more efficient use of trees. Additionally, by distributing the veneers in the manufacturing process, the effects of physical defects are very much diminished. Veneers are about 1/10th inch thick and are bound together with phenol formaldehyde or isocyanate exterior-type adhesives. As with LSL, LVL is manufactured in billets (3½"$_{max.}$ X 4' X 80'$_{max.}$). Finished products are then cut from these billets.

Manufacturer's literature (as of April 1999) indicated the following ESG values for the associated products:

Manufacturer & Product	**Load case**	**ESG**	
		Fastener Orientation	
		X-axis	Y-axis
Boise Cascade *Versa-Lam®*	Withdrawal	0.50[a]	0.50[a]
	DBS (nails & wood screws)	0.50[a]	0.50[a]
	DBS (bolts & lag screws)	-	0.50[a]
TrusJoist Macmillan *Microllam®*	Withdrawal	0.50	0.50
	DBS (nails & wood screws)	0.50	0.50
	DBS (bolts & lag screws)	-	0.50
Louisiana-Pacific *Gang-Lam®*	Withdrawal	0.47	0.50
	DBS (nails & wood screws)	0.39	0.46
	DBS (bolts & lag screws)	-	0.47
Willamette *StrucLam®*	Withdrawal	0.46	0.50
	DBS (nails & wood screws)	0.46	0.50
	DBS (bolts & lag screws)	-	0.50

[a] ESG values are determined from NDS-91. Designers should obtain updated data from the manufacturer.

Example 4: Laterally Loaded Connection Design for LVL

A sample floor plan is depicted in Figure 2. The plan calls for I-joists at 16" on center to tie into a LVL girder that spans the 20' length of the building. Joist hangers will support the free end of the I-joists. They are of 16-gage metal and are attached to the LVL girder. For a floor load of 40 psf live, 10 psf dead, determine the minimum number of 10d Common wire nails required for each joist hanger to safely support its joist. Assume a 3.5" wide, 18" deep, StrucLam® LVL girder.

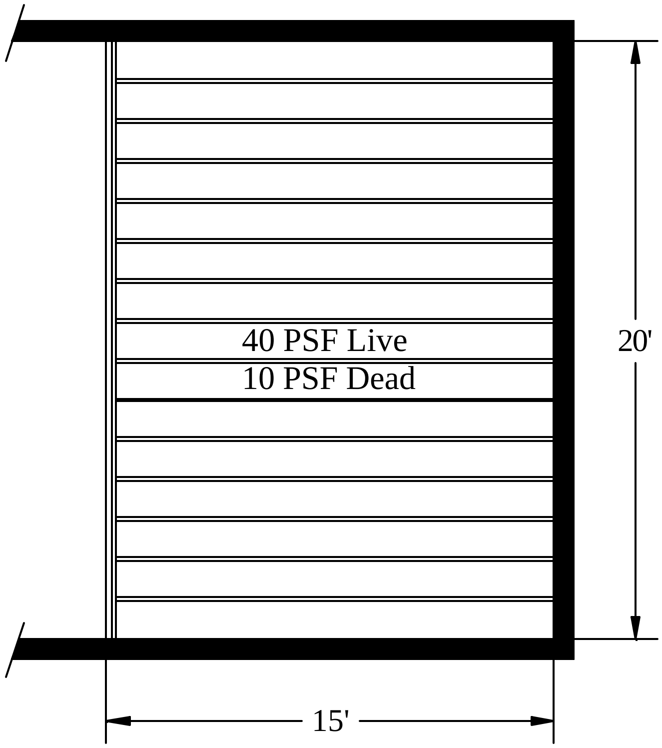

Figure 2. Floor plan for Example 5.

Given:

- 10d Common wire nails used
- Nail diameter (D) = 0.192”
- Nail length = 3.0”
- Hanger acts as Grade 33 side plate
- LVL girder is 3.5” thick ∏ penetration depth factor (C_d) = 1.0
- ESG for StrucLam® LVL = 0.50 for laterally loaded nail type fastener with Y-axis orientation
- From Table 12.3H of NDS-97, Z = 162 lb. for single shear connection with 16 gage plate in wood with ESG = 0.50

Solution:

Load distributed along joist:	16 in / 12 in/ft * (40 + 10) psf = 66.66 lb/ft
Reaction at hanger:	66.66 lb/ft * 15 ft / 2 = 500 lb
$Z' = Z * C_d$	162 * 1.0 = 162 lb
Minimum Number of Nails:	500 lb / 162 lb = 3.08
	Use 4, 10d Common nails

Parallel Strand Lumber

Parallel Strand Lumber (PSL) similar to its counterpart LSL. As a SCL, it consists of strands of timber that have been arranged in parallel order and glued together. By this process, physical defects are distributed throughout the product, reducing their cumulative effect. Some of the differences are that PSL makes use of higher-grade wood species. Also, the strands of lumber used come from veneer and tend to be 2' to 8' in length. Billets can be manufactured up to 11" X 20" X 66'. This makes the product ideal for beam and column applications. For outdoor use, PSL can be pressure preservative treated.

Manufacturer's literature (as of April 1999) indicates the following ESG values for the associated products:

Manufacturer & Product	**Load case**	**ESG**	
		Fastener Orientation	
		X-axis	Y-axis
TrusJoist Macmillan *Parallam®*	Withdrawal	0.50	0.50
	DBS (nails & wood screws)	0.50	0.50
	DBS (bolts & lag screws)	-	0.50

Note: Designers should obtain updated data from the manufacturer.

Example 5: Bolt Design for PSL Truss

A set of Gambrel trusses like the one shown in Figure 3, support the deck of a small bridge. The truss elements are 3 ½" X 9 ¼" Parallam® PSL, and have been pressure preservative treated for outdoor use. On each side of the truss members, steel plates ¼" thick hold the frame together. Assuming pinned connection behavior, determine the minimum number of bolts required to connect truss element CG at node C when a 10,000 lb load is applied at mid-span. Assume the example load case has "Normal duration"(C_D = 1.0).

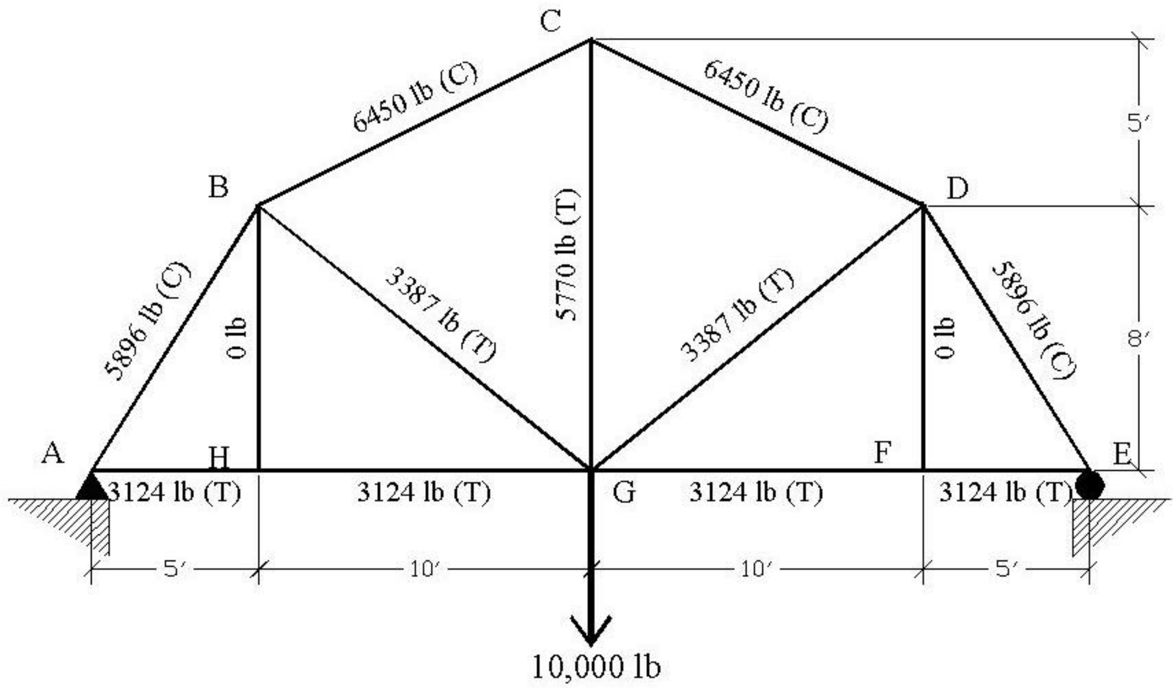

Figure 3. Gambrel truss with axial forces depicted.

Given:

- ½" bolts
- Main member thickness = 3½ "
- Loading is parallel to grain
- Assume number of fasteners in a row is 2 and the spacing is less than 4-inches, the group action factor (Cg) is calculated from NDS-97 Table 7.3.6C to be 0.99
- By statics, load in member CG = 5770 lb. (T)
- Duration factor (C_D) = 1.0
- Moisture correction factor (C_M) = 0.7 for > 19% Moisture Content
- ESG for Parallam® PSL = 0.50 for laterally loaded bolt type fastener with Y-axis orientation
- From Table 8.3B of NDS-97, $Z_{||}$ = 1510 lb. for double shear connection with ¼" plate side members

Solution:

$Z' = Z_{\|\|} * C_D * C_M * Cg$	1510 * 1.0 * 0.7 * 0.99 = 1,046 lb.
Minimum Number of Bolts:	5770 / 1046 = 5.52
	Use 6, ½" bolts

Conclusion

This paper has discussed methodology for determining Equivalent Specific Gravity for Structural Composite Lumber for use in connection design. ESG values allow SCL users to utilize NDS-97 connection design values developed for solid-sawn lumber. Composite lumber products constitute an ever-increasing portion of the timber construction industry. It is therefore important that practicing engineers be able to apply existing specifications and design procedures to the design of connections for the new SCL products. Examples were included both for determining and applying ESG to the design of various connections.

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TrusJoist MacMillan – Products include: TimberStrand® LSL, Microllam® LVL, Parallam® PSL, Wolmanized® Parallam® PSL. Website: http://www.tjm.com

Willamette Industries, Inc – Products include: StructLam® LVL. Website: http://www.wii.com