- *Calculate the required loaded edge distance for* $C_\Delta = 0.83$ and $C_\Delta = 1.0$.

$$E_\alpha = \frac{E_C E_D}{\sqrt{E_C^2 \sin^2(90-\phi-\alpha_{arm}) + E_D^2 \cos^2(90-\phi-\alpha_{arm})}} \qquad [2\text{-}19]$$

E_α = Required loaded edge distance
E_C = 5.5 in. for 2-5/8 in. shear plates and $C_\Delta = 1.0$
= 4.25 in. for 2-5/8 in. shear plates and $C_\Delta = 0.83$
= 7 in. for 4 in. shear plates and $C_\Delta = 1.0$
= 5.4 in. for 4 in. shear plates and $C_\Delta = 0.83$
E_D = 2.75 in. for 2-5/8 in. shear plates and $C_\Delta = 1.0$
= 1.5 in. for 2-5/8 in. shear plates and $C_\Delta = 0.83$
= 3.75 in. for 4 in. shear plates and $C_\Delta = 1.0$
= 2.5 in. for 4 in. shear plates and $C_\Delta = 0.83$

- *Determine the required spacing and loaded edge distance corresponding to the optimal geometry factor using linear interpolation.* If the optimal geometry factor is less than 0.83, use the minimum edge distance determined for $C_\Delta = 0.83$.

$$S_{\alpha,C_\Delta} = \left(\frac{C_\Delta - 0.5}{1-0.5}\right)\left(S_{\alpha,1.0} - S_{\alpha,0.5}\right) + S_{\alpha,0.5} \qquad [2\text{-}20]$$

$$E_{\alpha,C_\Delta} = \left(\frac{C_\Delta - 0.83}{1-0.83}\right)\left(E_{\alpha,1.0} - E_{\alpha,0.83}\right) + E_{\alpha,0.83} \qquad [2\text{-}21]$$

Choose spacing, *S*, and end distance, *E*, equal to or greater than those calculated. The chosen spacing and end distance should be rounded up to the nearest 1/16 in. or other practical unit of measure to facilitate fabrication.

- *Calculate the required depth based on connector spacing and edge distance:*

$$d'_c \geq d'_{c\ shear\ plates} = \left(n_y - 1\right) S_\alpha + 2E_\alpha \qquad [2\text{-}22]$$

Required crown depth based on flexure in the arm and chosen arm taper angle:

Estimating that the point of inflection occurs near the upper tangent point of the loaded arch for the unbalanced snow loading and that the crown depth is approximated by the depth required for the shear plates, the location of the critical section in the upper arm of the loaded arch (measured from the crown) can be determined from the following relationship, which was derived for this case from equation 4.32 of the AITC Timber Construction Manual (5th edition) (x is measured horizontally from the crown):

$$x \approx \frac{\cos(\phi)(L_R - x_2)\left(\dfrac{d'_c}{\cos(\alpha_{arm})}\right)}{2\left(d'_c \dfrac{\cos(\phi)}{\cos(\alpha_{arm})}\right) + \dfrac{(L_R - x_2)}{\cos(\phi)} \tan\alpha_{arm}} \qquad [2\text{-}23]$$

The required depth at that section can be approximated as:

$$d_x > \sqrt{\frac{3(\omega_S + \omega_D)(L_R - x_2)x\left(1 - \dfrac{x}{L_R - x_2}\right)}{bF_{bx}C_D C_I C_M C_t}} \qquad [2\text{-}24]$$

For tapered arms, the reference flexural stress, F_{bx}, used in [2-24] should be reduced to account for the loss of high strength material at the surface due to tapering, unless the arch is laid up with a uniform-grade lay-up or the high grade material is maintained throughout the length of the arch (Appendix A). Either of these options may increase the cost of the arch. For standard arches with tapered arms, a 10% reduction is suitable for preliminary design purposes.

The corresponding depth at the crown can be estimated as:

$$d_c > d_x - \left(\frac{x}{\cos\phi}\right)\tan\alpha_{arm} \qquad [2\text{-}25]$$

$$d'_c = \frac{d_c \cos(\alpha_{arm})}{\cos\phi_t} \qquad [2\text{-}26]$$

The greater depth from connector requirements or from arm flexure is chosen as the minimum depth of the arch at the crown.

With the preceding steps completed, a trial arch geometry is defined. The trial geometry should be further adjusted to ensure that the upper and lower tangent point depths are within approximately 10% of each other. The trial arch should be drawn to scale and the geometry should be adjusted if necessary for aesthetic considerations.

At this point, the preliminary design of the arch is completed. The final design must include a thorough analysis of the arch subject to all applicable loads and load combinations by the procedures discussed in Chapters 3-5. An example including the preliminary design procedure described in this chapter follows.

Example 2-1: Design of Tudor Arch

Given: A building with outside dimension of 50 ft by 60 ft is to be constructed using Southern Pine Tudor arches spaced at 15 ft.

The arches will be subject to normal temperatures and dry-use conditions.

The arches will be symmetric with a maximum roof height of 24 ft. and a wall height of 12 ft as shown in Figure E4.1.

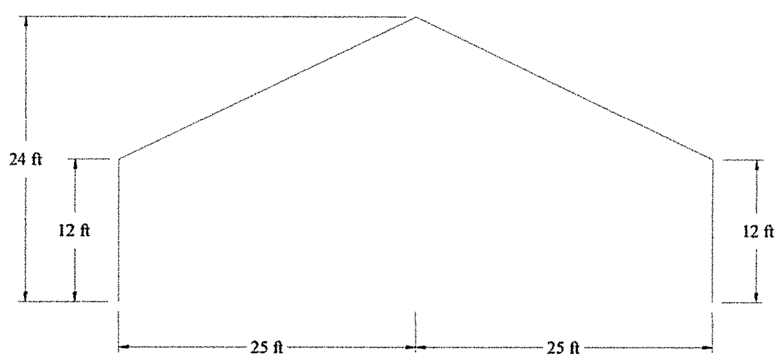

Figure E2.1. *Outside geometry of arch.*

The curved portion of the arches will have a radius of 10.5 ft at the inside face and a lamination thickness of ¾ in.

The arch has continuous lateral bracing along the wall and roof.

The building has no shear walls at the ends, so the arches will be assumed to support all vertical and lateral loads acting parallel to the planes of the arches.

Material Properties: $F_{bx}^{+} = 2000$ psi
$F_{vx} = 215$ psi

Loads: the loads have been determined as shown in Figures E2.2 through E2.4. The wall dead loads are assumed to act at the outer face of the arch.

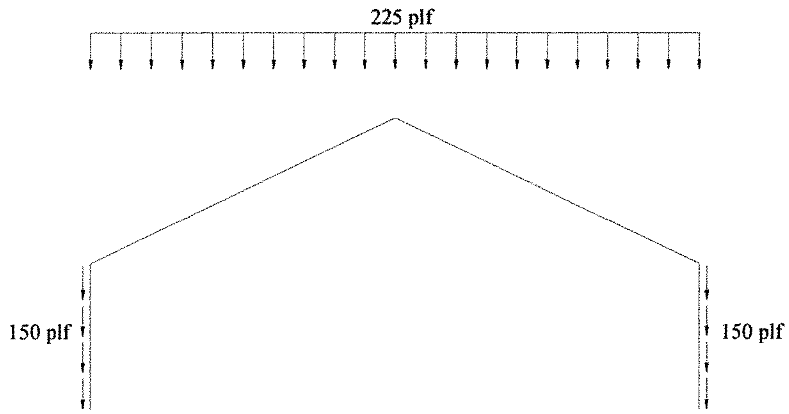

Figure E2.2. *Dead loads.*

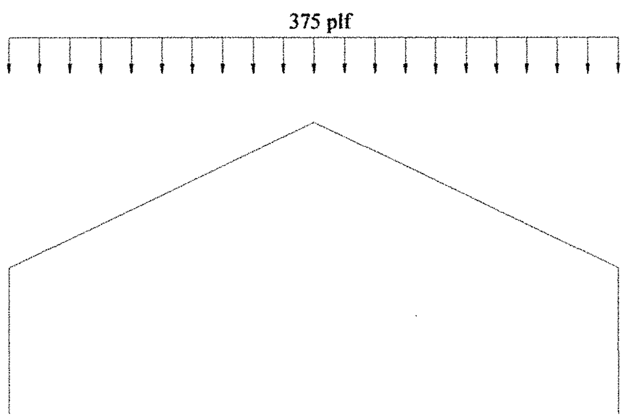

Figure E2.3. *Balanced snow load.*

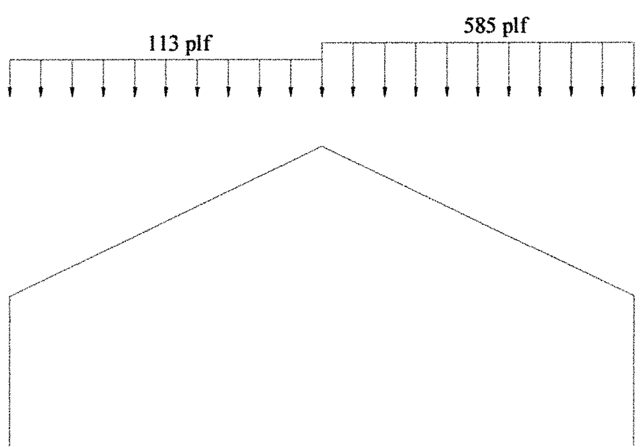

Figure E2.4. *Unbalanced snow load.*

Wanted: Perform preliminary design of a Tudor arch with a width of 6.75 in. based on the dead plus snow load combinations:

(1) **D** + **S** (balanced snow)
(2) **D** + **S** (unbalanced snow)

For final design, additional load combinations will need to be considered.

Solution:

The required depth at the lower tangent is commonly governed by the balanced snow loading. The depths in the arch arm are commonly controlled by the unbalanced snow loading.

Approximate reaction forces (using the outside arch geometry) for each considered snow load combination are included in Table E2.1.

Table E2.1. *Approximate reactions for* **D + S** *load combinations.*

Load	$R_{y,L}$	$R_{x,L}$	C_y	C_x	$R_{y,R}$	$R_{x,R}$
D+S (Balanced)	16800	7810	0	-7810	16800	7810
D+ S (Unbalanced)	13200	7470	-2950	-7470	19100	7470

Estimating the required depth at the crown based on connection requirements

The minimum depth at the crown will be estimated based on the vertical reaction force at the peak connection due to unbalanced snow loading and the number of shear plates required to transfer the load.

For 4 inch shear plates in Southern Pine:

$$P = 4360 \text{ lb}$$
$$Q = 3040 \text{ lb}$$
$$Q_{90} = 0.6Q = 0.6(3040 \text{ lb}) = 1824 \text{ lb}$$

The shear plates will be loaded at an angle to the grain of $90° - \phi - \alpha_{arm}$.

$$\phi = \arctan\left(\frac{12 \text{ ft}}{25 \text{ ft}}\right) = 25.64°$$
$$\alpha_{arm} = 2.5°$$
$$90° - \phi - \alpha_{arm} = 90° - 25.64° - 2.5° = 61.86°$$