DESIGN CALCULATIONS – JOIST REPAIR KIT

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Rev 1

Projection Name: Joist Repair Kit Design Calculations

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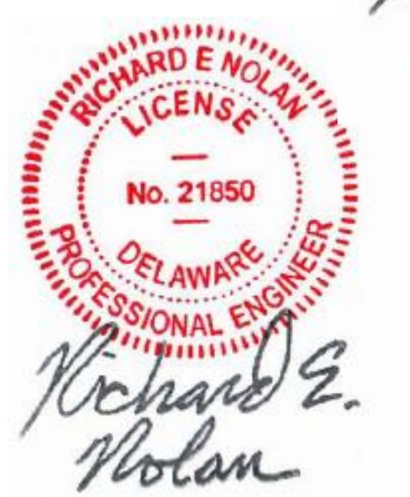


Product Description

This product is designed to restore the full strength of notched or drilled floor joists assuming the joist wood species is Douglas-Fir #2 (DF) or a weaker wood species such as Spruce Pine Fir (SPF) #2; the recovery of full strength to the floor joist also assumes that the original joist span was per the 2020 and 2021 International Residential Code (IRC). Also, a certain amount of material must remain above or below the notch as specified in Table 2; other assumptions are listed below.

Certain notching and drilling of floor joists are acceptable per most building codes such as the IRC. However, notching or drilling in access of what is permitted by the code could result in weakening the joist beyond its ability to safely support the floor loads. When the joist repair strap is installed at the bottom of a notched floor joists, the strap transmits the tension load that is generated back into the remaining wood at either side of the notch. The strap is also able to restore the full strength of a drilled or otherwise similarly damage floor joist.

It should be noted that multiple steel straps on the same floor joists may be used if the straps do not overlap. Also, the straps may be used on as many adjacent floor joists as required.

Abbreviations

DF, Douglas Fir

SPF, Spruce Pine Fir

PSF, Pounds per Square Foot

PLF, Pounds per Linear Foot

PSI, Pounds per Square Inch

IRC, International Residential Code

#, Pounds

Assumptions

- Any structural benefits resulting from the attached floor sheathing is ignored, this is a conservative assumption as the attached floor sheathing will likely strengthen the floor system.
- Maximum floor joists spacing is per 2020 and 2021 International Residential Code span charts.
- The floor dead load is assumed to be 10 PSF and live load to be 40 PSF.
- Typical floor joists are Spruce-Pine-Fir (SPF)#2 or Douglas-Fir (DF)#2 the analysis is bounded for by the use of DF which has higher design values
- The maximum width of the notch is limited to six inches.
- The calculations provided to demonstrate the notch repair are also applicable to repairing a hole in a joist since a hole is less structurally damaging than a notch of the same size since some wood material (although perhaps minimal) surrounds the hole adding strength which is not the case for a notch.

DESIGN CODE REFERENCES

Reference (a): National Design Specification (NDS) for Wood Construction - 2018

Reference (b): American Institute of Steel Construction (AISC) – Thirteenth Edition

Reference (c): 2020 and 2021 International Residential Code (IRC)

Analysis

Per Table 4A of Reference (a) the reference design value of Douglas Fir-Larch No. 2 is 900 psi and the shear value is 180 psi. For a typical joist the adjustment factors are load duration factor, size factor and repetitive use factor. The size factors are listed in Table 1 below and are dependent on the depth of the joists.

Table 1 – Size Adjustment Factor

Member Size	**Size Factor**
2x6	1.3
2x8	1.2
2x10	1.1
2x12	1.0

The load duration factor used for the floor joist is 0.9 for dead and 1.0 for live load. The repetitive use factor is 1.15.

A load duration factor of 1.0 (live load) is used since this results in the highest stress, the maximum permitted bending stress in a rafter would be

$$Fb = 900 \times 1.0 \times 1.15 \times 1.3 = 1{,}346 \text{ psi (for a 2x6) and}$$

$$Fb = 900 \times 1.0 \times 1.15 \times 1.0 = 1{,}035 \text{ psi (for a 2x12)}$$

$$Fb = 875 \times 1.0 \times 1.15 \times 1.0 = 1{,}006 \text{ psi (for a 2x12) for SPF}$$

The bending stress is equal to Fb = Mc/I where M is the bending moment, c is half the depth of the member and I is the area moment of the member. Solving for the bending moment M:

$$M = Fb \times I / c$$

The cross-section area moments are computed below:

$$I_{(2x6)} = (1/12) \times 1.5 \times 5.5^3 = 20.8 \text{ in}^4 \text{ (for a 2x6)}$$

$$I_{(2x12)} = (1/12) \times 1.5 \times 11.25^3 = 178.0 \text{ in}^4 \text{ (for a 2x12)}$$

The half depth of a 2 x 6 and 2 x 12 are computed below:

$$c_{(2x6)} = 5.5 / 2 = 2.75 \text{ in}$$

$$c_{(2x12)} = 11.25 / 2 = 5.63 \text{ in}$$

The bending moments are computed below:

$$M = 1{,}346 \times 20.8 / 2.75 = 10{,}181 \text{ in \# (for 2 x 6)}$$

$$M = 1{,}035 \times 178 / 5.63 = 32{,}723 \text{ in \# (for 2 x 6)}$$

The tension in the strap at the bottom of the notched member where the strap is installed is computed below and is equal to the bending moment divided by the depth of the member.

$$T = M / d$$

$$T = 10{,}181 \text{ in \#} / 5.5 \text{ in} = 1{,}851\text{\# (for 2 x 6)}$$

$$T = 32{,}723 \text{ in \#} / 11.25 \text{ in} = 2{,}909\text{\# (for 2 x 12)}$$

Tension in strap

Strap material is A36 with a minimum tensile strength of 36,000 psi. The strap is 1/8-inch-thick and 1.25 inches wide. The diameter of the holes are 0.25 inches. The minimum cross-sectional area is at a hole location and is calculated below.

$A = 0.125 \times (1.25 – 0.25) = 0.125 \text{ in}^2$

The maximum safe tensile force in the steel strap assuming 66% of the yield strength is calculated below:

$T = 0.66 \times 36{,}000 \text{ psi} \times 0.125 \text{ in}^2 = 2{,}970$ #

Shear in Wood

This section calculates the required depth of wood remaining above the notch for the member to have acceptable remaining shear strength. The shear strength of concern in the wood member is transverse shear stress. The formula used to calculate the transverse shear stress is provided below 1.1)

$$\sigma_V = \left(\frac{3}{2}\right)\frac{V}{A} \text{ Equation (1.1)}$$

Where V, is the end reaction in the member and "A" is the cross-sectional arear of the material remaining above the notch. Since floor joists are 1.5 inches wide, equation (1.1) can be rewritten as:

$$\sigma_V = \left(\frac{3}{2}\right)\frac{V}{1.5\ x\ d_r} \text{ Equation (1.2)}$$

Where "d_r" is the depth of the material remaining above the notch. The end reaction "V," is equal to half of the product of the distributed load on the floor joists, the length/span of the floor joist and the spacing as shown below.

Solving Equation 1.2 for the minimum depth of material remaining "d_r," yields:

$$d_r = \left(\frac{3}{2}\right)\frac{V}{1.5\ x\ \sigma_V} \text{ Equation (1.3)}$$

V = 1.33 x Q x Span / 2 Equation (1.4)

Where "Q" is the distributed load on the floor joists. The reaction at the end of the beam will be maximum when the floor joists is at its maximum span. Table 1 below lists the maximum span of Douglas Fir #2 and Spruce Pine Fir #2 Per Table R502.3.1(2) of Reference (a). The end reaction is also provided in Table 1 using equation (1.4). Per Reference (b) (NDS), the allowable transverse (parallel to grain) shear stress for D.F. # 2 is 180 psi and for SPF #2 135 psi. Equation 1.3 is solved for the d_r for the different sized floor joists and wood species using the end reaction force and allowed sheared stress. A sample calculation for a 2x6, SPF #2 is provided below.

Maximum span of 2x6 SPF #2 per Reference (a): 9.3'

V= 1.33 x 50 PSF x 9.3' / 2 = 310#

Table 2 – maximum floor joists spans and minimum required material remaining above notch

Joist Size	D.F.#2 Max Span FT	SPF #2 Max Span FT	D.F. #2 End Reaction #	SPF #2 End Reaction #	D.F. #2 min. notch remaining in.	SPF #2 min. notch remaining in.
2x6	9.8	9.3	327	310	1.8	2.3
2x8	12.8	12.3	427	410	2.4	3.0
2x10	15.6	15.4	520	513	2.9	3.8
2x12	18.1	17.8	603	593	3.4	4.4

STRENGHT OF MATERIAL REMAINING ABOVE NOTCH

The material remaining above the notch experiences axial compression from the bending moment developed in the joist and the bending moment from the floor load. The minimum material left above the notch per Table 2 is 1.8 inches. The maximum length of the notch is 6 inches. The material remaining over the notch experiences both bending from the floor loads and axial compression from the moment developed in the joist. Therefore, the combined bending and axial loading equations of section 3.9 of reference (a) must be satisfied.

The bending moment in the material remaining above the notch is calculated below, using a dead weight of 10 PSF and a live load of 40 PSF.

$$M = (QxL^2) / 8$$

Where Q, is the distributed load adjusted for joist spacing of 16" = (10PSF + 40PSF) x 1.33' = 66.67 PLF. "L," is the length of the notch (0.5').

$$M = (66.67 \times 0.5^2) / 8 = 2.1 \text{ ft \#}$$

SPF has a lower minimum modulus of elasticity compared to DF and this value is therefore used in the calculations.

The bending stress in the material remaining above the notch is calculated below.

$f_{b1} = MC / I$

Where, “M” is the bending moment calculated above, “C” is half the depth of the material remaining above the notch (1.8 / 2 = 0.9”) and “I” is the section modulus of the material remaining above the notch as calculated below.

$I = (1/12) \times b \times d_1^3 = (1/12) \times 1.5 \times 1.8^3 = 0.73\ in^4$

f_{b1} = 2.1 ft # x 0.9” / 0.73 in^4 x (12”/ft) = 31 psi

E_{min} = 510,000 psi (SPF 2)

The minimum dimensions of the material remaining above the notch are provided below.

d_1 = 1.8” (wide face dimension)

d_2 = 1.5” (narrow face dimension)

The section 3.9 equations from reference (a) that must be satisfied are provided below.

$$\left[\frac{f_c}{F'_c}\right]^2 + \frac{f_{b1}}{F'_{b1}\left[1 - \left(\frac{f_c}{F_{cE1}}\right)\right]} + \frac{f_{b2}}{F'_{b2}\left[1 - \left(\frac{f_c}{F_{cE2}}\right) - \left(\frac{f_{b1}}{F_{bE}}\right)^2\right]} \leq 1.0$$

And

$$\frac{f_c}{F_{cE2}} + \left(\frac{f_{b1}}{F_{bE}}\right)^2 < 1.0$$

Where:

f_{b1} = actual edgewise bending stress (bending load applied to narrow face of member), psi = 31 psi as calculated above.

f_{b2} = actual flatwise bending stress (bending load applied to wide face of member), psi = 0 since no load applied in this direction.

Equation 3.9-3 is re-written below with f_{b2} set equal to zero since there is no flatwise bending stress.

$$\left[\frac{f_c}{F'_c}\right]^2 + \frac{f_{b1}}{F'_{b1}\left[1 - \left(\frac{f_c}{F_{cE1}}\right)\right]} \leq 1.0$$

$$f_c < F_{cE1} = \frac{0.822\ E'_{min}}{(l_{e1}/d_1)^2}$$

E'_{min} = 1.0 x E_{min} = 510,000psi since no relevant adjustment factors apply.

f_c, is the actual compression stress in the member. The maximum compressive stress in the material remaining above the notch is 2,909# divided by the cross-sectional area of the material remaining above the notch as calculated below.

f_c = 2,909# / (1.5" x 1.8") = 1,077 psi

$$f_c < F_{cE1} = \frac{0.822\ (510{,}000psi)}{(6"/1.8")^2} = 37{,}730psi$$

1,077 psi < 37,730 psi

$$f_c < F_{cE2} = \frac{0.822\ (510{,}000psi)}{(6"/1.5")^2} = 26{,}201psi$$

1,077 psi < 26,201 psi

$$\mathrm{F_{bE}} = \frac{1.20\ \mathrm{E'_{min}}}{\mathrm{R_B^2}}$$ Equation 3.3-5 or reference (a)

$$R_B = \sqrt{\frac{l_e d}{b^2}} = \sqrt{\frac{6"(1.8")}{1.5"^2}} = 2.2$$

$$\mathrm{F_{bE}} = \frac{1.20\ (510{,}000\mathrm{psi})}{2.2^2} = 126{,}446\ \mathrm{psi}$$

The reference design value bending stress, F_b for SPF is 875 psi per table 4 of reference (a).

There are no adjustment factors that apply, therefore, F_b' = F_b = 875 psi.

The reference design value compressive stress parallel to the grain, F_c for SPF is 1150 psi per table 4 of reference (a).

There are no adjustment factors that apply, therefore, $F_c' = F_c = 1150$ psi.

The reference (a) combined bending and axial load equations are calculated below.

$$\left[\frac{1077psi}{1150psi}\right]^2 + \frac{31psi}{875psi(1-(\frac{1077psi}{37730psi})} = 0.91 < 1.0$$

$$\frac{1077psi}{26201psi} + \left(\frac{31psi}{126{,}446psi}\right)^2 = 0.04 < 1.0$$

Both equations are less than unity, therefore, the material remaining above the notch is acceptable for bending and the axial load.

Strength of Fastener with Steel Side Plate

The fasteners used are Simpson Strong-Tie SDS25212 which are ¼" diameter screws that are 1.5 inches in length. Per Figure 1 below, the shear strength for the 10 gauge or greater steel side plate is 250# for Douglas-Fir and 180# for Spruce-Pine-Fir. The steel strap is equivalent to 11 gauge. There are 16 screws used in each end of the strap, therefore the strength provided by the screws is 16 x 250# = 4,000# for DF and 16 x 180# = 2,880# for SPF which is greater than the required 2,970# for DF and 2,827# for SPF.

Simpson Strong-Tie® Fastening Systems

Load Tables, Technical Data and Installation Instructions

SIMPSON Strong-Tie

Strong-Drive®
SDS HEAVY-DUTY CONNECTOR Screw

Heavy-Duty Simpson Strong-Tie® Connectors

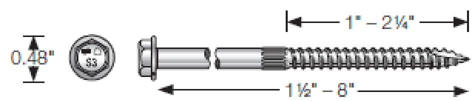
The Simpson Strong-Tie® Strong-Drive® SDS screw is a ¼" diameter high-strength structural wood screw ideal for various connector installations as well as wood-to-wood and EWP fastening applications.

Install Tips: A low-speed ½" drill with a ⅜" hex driver (BITHEXR38-134) is the recommended tool for installation.

Codes/Standards: ICC-ES ESR-2236; City of L.A. RR25711, State of Florida FL9589

U.S. Patents 5,897,280; 7,101,133

For More Product Information, see p. 75



SDS – Allowable Shear Loads-Steel Side-Plate Applications

Size (in.)	Thread Length (in.)	Coating/ Material	Model No.	DF/SP Allowable Shear Loads (lb.) Steel Side Plate Thickness, mil (ga.)			SPF/HF Allowable Loads (lb.) Steel Side Plate Shear, mil (ga.)		
				54 (16)	68 and 97 (14 and 12)	123 (10) or greater	54 (16)	68 and 97 (14 and 12)	123 (10) or greater
¼ x 1½	1	Double-barrier coating	SDS25112	250	250	250	180	180	180
¼ x 2	1¼		SDS25200	250	290	290	180	210	210
¼ x 2½	1½		SDS25212	250	390	420	180	280	300
¼ x 3	2		SDS25300	250	420	420	180	300	300
¼ x 3½	2¼		SDS25312	250	420	420	180	300	300
¼ x 4½	2¾		SDS25412	250	420	420	180	300	300
¼ x 5	2¾		SDS25500	250	420	420	180	300	300
¼ x 6	3¼		SDS25600	250	420	420	180	300	300
¼ x 8	3¼		SDS25800	250	420	420	180	300	300
¼ x 1½	1	Type 316 stainless steel	SDS25112SS	250	250	250	180	180	180
¼ x 2½	1½		SDS25212SS	250	390	420	180	280	300
¼ x 3	2		SDS25300SS	250	420	420	180	300	300
¼ x 3½	2¼		SDS25312SS	250	420	420	180	300	300

1. Screws may be provided with the 4CUT™ or Type-17 point.
2. Allowable loads are shown at the wood load duration factor of C_D = 1.00. Loads may be increased for load duration up to a C_D = 1.60.
3. Allowable withdrawal load for DF/SP/SCL is 172 lb./in. and for SPF/HF withdrawal is 121 lb./in. Total withdrawal load is based on actual thread penetration into the main member.
4. LSL wood-to-wood applications that require 4½", 5", 6" and 8" SDS screws are limited to interior-dry use only.
5. Minimum spacing requirements are listed in ICC-ES ESR-2236.

Figure 1 – Simpson Strong-Tie Page 329 of Technical Information

CONCLUSION

The joist repair strap has been designed to restore the strength of any size floor joists of either SPF #2 or DF #2 with spans up to the maximum allowed per the span tables provided in the 2020 and 2021 International Residential Code. The following items were demonstrated to be structurally acceptable by analysis or using tables.

- Ability of the strap to withstand the tension force
- Ability of the screws to withstand the tension force
- The acceptability in the material remaining above the notch to support both the floor load and the compression developed from the bending moment in the joist simultaneously
- The ability of the material remaining above the notch to support the shear load developed in the joist

I certify that when properly installed, the joist repair strap will restore the full intended strength of a floor joists within the assumptions and limitations provided herein.