Part 2: Evaluation and Modification of Open Web Steel Joists and Joist Girders

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Description

This is part two of a two-part series to discuss and demonstrate the methods to modify existing open web steel joists and Joist Girders for revised loading conditions. This webinar parallels the Steel Joist Institute publication, Technical Digest No. 12 “Evaluation and Modification of Open Web Steel Joists and Joist Girders.”

Learning Objectives

- Give several methods and practices to modify existing joists to increase the load-carrying capacity
- Provide details that are commonly used to increase the load-carrying capacity of a joist component
- Address the realistic limits of modifications with alternatives when modifications are not possible
- Show examples where the joist lengths are altered

Introduction

- Commercial manufacturing of open web steel joists began in 1923
- The Steel Joist Institute was formed in 1928
  - Open Web Steel Joist use has continued to grow
  - There are millions of Open Web Steel Joists in service

Introduction (cont'd)

- Evaluation and Modification of joists are required for many reasons
- Building renovations
- Addition of roof top units
- Conveyor loads
- Field deviations – Dimensional changes
- Other changes not contemplated in the original design
- Damage to the joists

Introduction (cont'd)

Know when to say NO!

Know when to say YES

Resources Available

- New 2020 Specification
- Revised SJI Technical Digest No. 12
  - Present procedures
  - Suggest details for modification or strengthening
- SJI design tools for the reinforcement of the joist members.

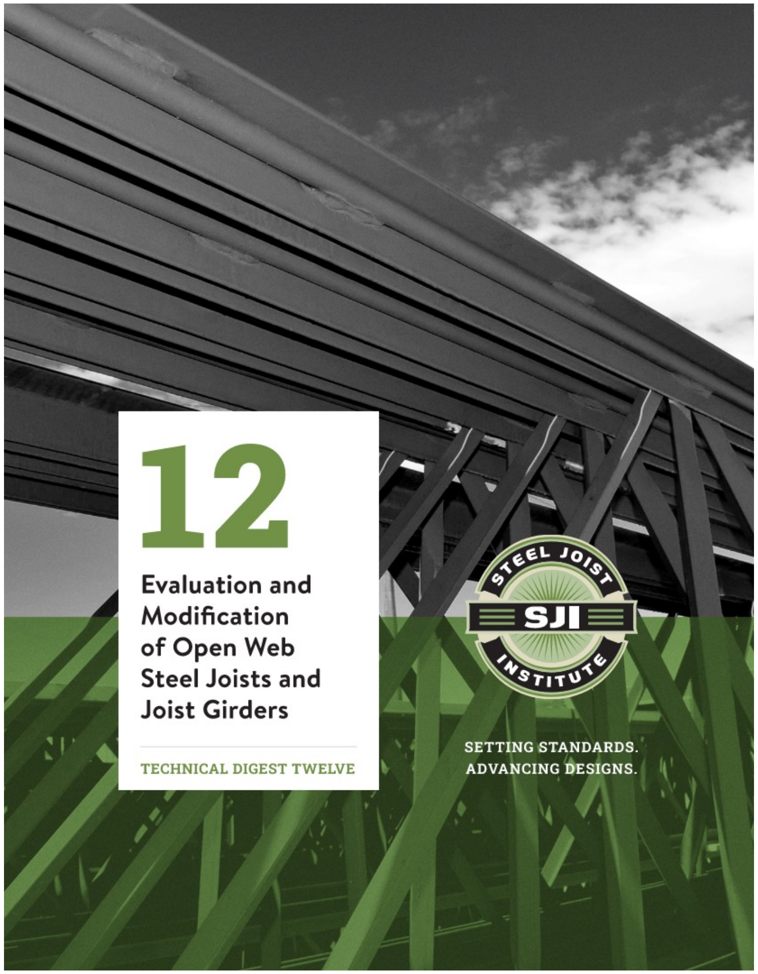
2020 SJI Specification

- Combined Standard Specifications (ANSI SJI 100-2020) for K, KCS, LH, DLH, G
- Load Capacity Tables
  - K-Series Load Tables
  - KCS Joists
  - LH- and DLH-Series Load Tables (Newly Expanded LH)
  - Joist Girder Weight Tables
- Order from: www.steeljoist.org
  Free download – Pay for hardcopy

SJI Technical Digest No. 12

Evaluation and Modification of Open-Web Steel Joists and Joist Girders

- Present procedures
- Suggest details for modification or strengthening



Price: $30

Order from: www.steeljoist.org

SJI Reinforcing Design Tool

TOP CHORD REINFORCEMENT		
Reinforcement Type	**Best Usage**	**Tab**
Load Distribution	When an added load slightly exceeds the joist available strength, a load distribution beam may eliminate the need for reinforcement.	Load Dist
Top Chord with Rods	Use for all chord sizes when the web system consists of rods or crimped angles. May also use by clipping the web angles on double-angle web systems.	TC-Rods
Top Chord with Horizontal Plates	Use for chords with legs equal to or greater than 3 inches and when the web system consists of rods or crimped angles.	TC-Horiz PL's
Top Chord with Box Angles	Use for chords with legs equal to or greater than 3 inches and when the web system consists of rods or crimped angles.	TC-Box L's
Top Chord with Outset Angles	Use with double angle webs.	TC-Out L's
Top Chord with Top Angles	Use before deck is installed.	TC-Top L's
Top Chord with Bottom Angles	Use for all chord sizes when the web system consists of rods or crimped angles.	TC-Bot L's

TOP CHORD REINFORCEMENT		
Reinforcement Type	**Best Usage**	**Tab**
Top Chord with Sloped Plates	Use for chords with legs equal to or greater than 4 inches and when the web system consists of rods or crimped angles.	TC-Sloped PL's
Top Chord with Vertical Plates	Use for all chord sizes when the web system consists of rods or crimped angles or when the chord leg is long enough for plate to clear web angles on double-angle web systems.	TC-Vert PL's

BOTTOM CHORD REINFORCEMENT		
Reinforcement Type	**Best Usage**	**Tab**
Bottom Chord in Tension with Plate	Use for all bottom chord sizes in tension.	BC-T-PL
Bottom Chord in Compression with Plate	Use for all bottom chord sizes in compression.	BC-C-PL
Bottom Chord in Tension with Rods	Use for all bottom chord sizes in tension when the web system consists of rods or crimped angles. May also use by clipping the web angles on double-angle web systems.	BC-T-Rods
Bottom Chord in Compression with Rods	Use for all bottom chord sizes in compression when the web system consists of rods or crimped angles. May also use by clipping the web angles on double-angle web systems.	BC-C-Rods

WEB REINFORCEMENT		
Reinforcement Type	**Best Usage**	**Tab**
Angle Web with Sloped Plates	Use for reinforcing double web angles.	L Web-Sloped PL's
Angle Web with Rods	Use for reinforcing double web angles.	L Web-Rods
Angle Web Strut	Use for adding a new single angle or double angle web member. Applicable for all web systems.	L Web Strut

SJI EXISTING WEB MEMBER STRENGTH CALCULATIONS		
Member Type	**Best Usage**	**Tab**
Rod Web	Use for determining the strength of an existing rod web in a joist or Joist Girder.	Rod Web
Crimped Angle	Use for determining the strength of an existing crimped angle web in a joist or Joist Girder.	Crimp L

SJI Reinforcing Design Tool

Joist Top Chord with Rod Reinforcement

(SJI Specification / AISC Specification 360-16 - ASD)

Project Name:	SJI TD 12 Design Example	Date:	9/17/2020
Project Number:		Engineer:	

Design Methodology	ASD
Member Type	Joist

Input Data												
Leg Length	Leg Thk	Gap	Rod Dia	F_y	Preload	Comp Fy	# of	End	Panel Lgth	Compression	M_{pos}	M_{neg}
in.	in.	in.	in.	ksi	kips	ksi	Fillers	Panel (1)	in.	kips	kip-in.	kip-in.
3	0.25	1	1	50	0.0	50.0	1	No	24	100.0	3.0	2.0

(1) End panels are between the bearing seat and first interior primary panel point comprised of at least two intersecting web members.

All calculated properties are for double angles and reinforcement except as noted										
Member	A	y_{bar}	I_x	r_x	I_y	r_y	I_z (2)	r_z (2)	S_{top}	S_{bot}
	$in.^2$	in.	$in.^4$	in.	$in.^4$	in.	$in.^4$	in.	$in.^3$	$in.^3$
Top chord	2.875	0.842	2.488	0.930	7.669	1.633	0.504	0.592	2.954	1.153
Rods	1.571	0.750	0.098	0.250	2.553	1.275	0.049	0.250	0.196	0.196
Composite	4.446	0.810	2.595	0.764	10.222	1.516	0.561	0.502	3.205	1.185

(2) Values for single members.

SJI Effective Length Factors									
Interior Panels	K_x	K_y	K_z	K_s (3)	End Panels	K_x	K_y	K_z	K_s (3)
Two shapes w/ fillers	0.75	0.94	-	1.00	Two shapes w/ fillers	1.00	0.94	-	1.00
Two shapes no fillers	-	-	0.75	-	Two shapes no fillers	-	-	1.00	-
Single members	0.75	0.94	-	-	Single members	1.00	0.94	-	-

(3) K_s applies to r_z values between fillers.

Slenderness Ratios	SJI Unreinforced Nominal Axial Stress					AISC Reinforced Nominal Axial Stress				
	K	KL/r	F_e	QF_y/F_e	F_{cr}	K (4)	KL/r	F_e	F_y/F_e	F_{cr}
	-	-	ksi	-	ksi	-	-	ksi	-	ksi
$(KL/r)_x$	0.75	19.3	765	0.06	46.8	1.00	31.4	290	0.17	46.5
$(KL/r)_y$	0.94	20.7	667	0.07	46.6	1.00	23.7	508	0.10	48.0
$(KL/r)_z$ w/ fillers	1.00	20.3	697	0.07	46.7	1.00	23.9	502	0.10	48.0
$(KL/r)_z$ no fillers	0.75	30.4	310	0.16	45.0	1.00	47.8	125	0.40	42.3

(4) Users may elect to use smaller or larger K values based on their judgment.

Torsional and Flexural-Torsional Buckling					
Section	Fe	Fy/Fe	Fcr	Pn	Pn/Ω
	ksi	-	ksi	kips	kips
N/A	N/A	N/A	N/A	N/A	N/A

SJI Unreinforced Section Strength											
Between Panel Points									At Panel Point		
fa	fb	Fcr	Fcr/Ω	Fy/Ω	Cm	F'e	1-1.67fa/F'e	Eq. 9 or 10	fa	fb	(fa+fb)/(Fy/Ω)
ksi	ksi	ksi	ksi	ksi	-	ksi			ksi	ksi	
34.8	1.02	46.6	27.9	29.9	0.970	764.6	0.92	1.28	34.8	1.73	1.22

REINFORCEMENT IS REQUIRED

AISC Reinforced Section Strength										
Between Panel Points							At Panel Point			
Pr	Mr	Fcr	Pc/Ω	Mc	Mc/Ω	Eq. H1-1a or H1-1b	Pr	Mr	Mc/Ω	Eq. H1-1a or H1-1b
kips	kip-in.	ksi	kips	kip-in.	kip-in.		kips	kip-in.	kip-in.	
100.0	3.0	46.5	123.8	59.2	35.5	0.88	100.0	2.0	35.5	0.80

Rod Welds		
Weld strength, F_{EXX}	70	ksi
Stitch weld length	2	in.
Stitch weld spacing	12	in.
Weld throat (5/16 x rod radius)	0.156	in.
Required force per rod	17.7	kips
Available weld strength	3.28	kips/in.
Required end weld length/rod	5.38	in.

Buckling of Rods between Welds		
Effective length	6.5	in.
Slenderness ratio	26.0	
Fe	423.4	ksi
Fcr	47.6	ksi
Fcr/Ω	28.5	ksi
Strength per rod	22.4	kips
Strength ratio	0.79	

SJI Technical Digest No. 12

Summary of Part 1

- Reviewed identification of the existing joists
- Reviewed design assumptions for existing joists
- Reviewed an example where additional concentrated loads were added to an existing joist
- Reviewed methods of specifying loads to minimize future repairs
- Reviewed the length and placement of welds
- Reviewed the risk of repair verses the in-place capacity of a joist

Joist Investigation Form

Steel Joist Institute Assistance

- Fill out the Form Online
- Download from SJI website
  - https://steeljoist.org/find-existing-joists/
  - Return to SJI office or manufacturer for assistance
- Appendix A of TD 12

STEEL JOIST INSTITUTE

steeljoist.org

Please complete the following form and email it to sji@steeljoist.org or fax it to 843-407-4044.

Date: ______________________

Name: ____

Company: ____

Phone: ______________________Fax:__________________Cell:_____________

Email: ____

Project Details

Jobsite Location City/State: ____

Project Name: ____

Why are you requesting this information? Select all that apply.

☐ Evaluation ☐ Field or erection problem ☐ Inspection ☐ Legal issue

☐ New construction ☐ Rehabilitation or reuse ☐ Seismic retrofit

☐ Structural problem ☐ Other, describe ____________________________________

Supplementary Information

What year was the building constructed or approximate age of the structure? ____________

Who was the joist manufacturer? ____

Is there a tag on the joist? ☐ No ☐ Yes, provide tag information

____

What type of trusses are the joists? ☐ Warren ☐ Modified Warren ☐ Pratt

☐ Other, describe or sketch

____

What are the joists used for? ☐ Roof loading ☐ Floor loading

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Analysis Considerations

To Analyze a Joist

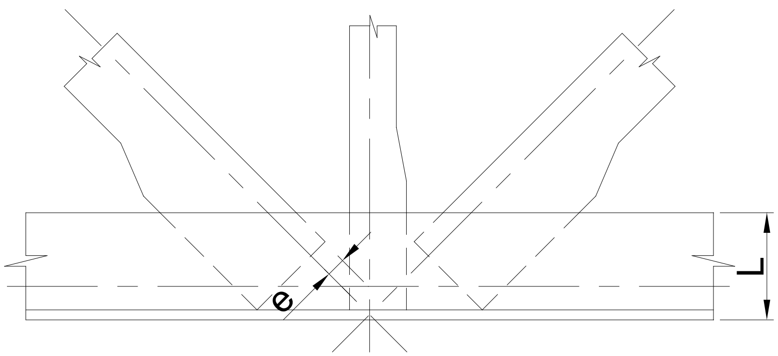
- Pinned end connections are used for web members
- Specifications for K-Series joists changed in the 2015 SJI spec.
    - Prior to 2015 local bending in K-Series joist top chord panels from uniformly applied loads was neglected provided the panel length did not exceed 24".
    - In 2015 the bending from uniformly applied loads are required to be included in the joist analysis/design, regardless of the panel spacing.
    - The K factors for the slenderness ratio calculations were changed.
- Consequently, a decision needs to made regarding which spec to use for the joist evaluation.

Analysis Considerations (con't)

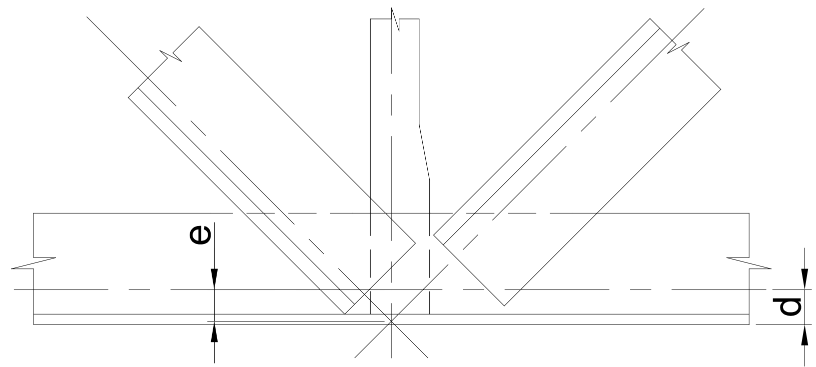
To Analyze Joist Capacity

- A first-order analysis is used
- Web eccentricities may need to be considered. Reference SJI specification 4.5.4 for "single component web members" (crimped angle or rod webs) and "web member composed of at least two shapes" (double angle webs).

Web Eccentricity



TD #11 Figure 1.10 &
SJI Spec Figure 4.5-1



TD #11 Figure 1.11
SJI Spec Figure 4.5-2

Single component or rod web members (crimped web angles)

$e \leq 0.75L$

Web member composed of at least two shapes (double angle web members)

$e \leq 1\frac{1}{2}d$

Reinforcing / Replacing / Adding

Considerations:

- Cost
- Time
  - Engineering and labor for field reinforcement.

    vs.
  - Manufacturing and Installation of a new joist
- Difficulty of repair - Interferences, Access
- Effectiveness of Reinforcing
- Skill of workman

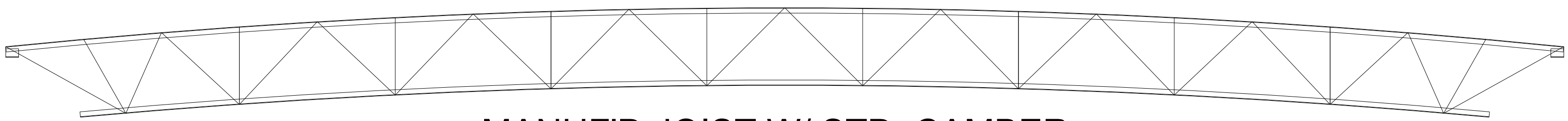
Reinforcing / Replacing / Adding

Considerations:

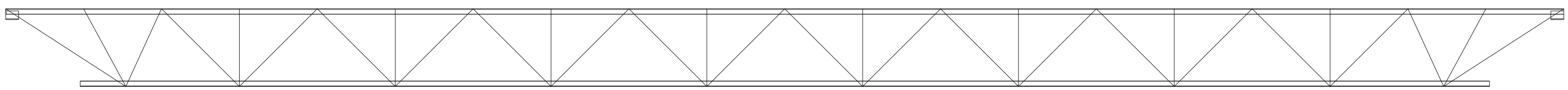
- Existing interferences
  - Piping, electrical conduits, other interferences
  - Removing or relocating could be at a greater expense than reinforcement
- Camber
  - May need to reduce camber in new joists
  - Joists can be ordered with shallower seat depths and then shimmed in the field
  - The joist can be supplied with a splice so two individual pieces can be installed and bolted together.
- Lateral Stability of the joist top chord
  - Shoot pins through the chord, decking, and slab
  - Rely on bridging to provide lateral support

Reinforcing / Replacing / Adding

Camber – Joists manufacturers rigging tables are set up for SJI standard camber. (Ref. SJI Spec Table 4.6-1). If replacing or adding a joist, specify zero or no camber.



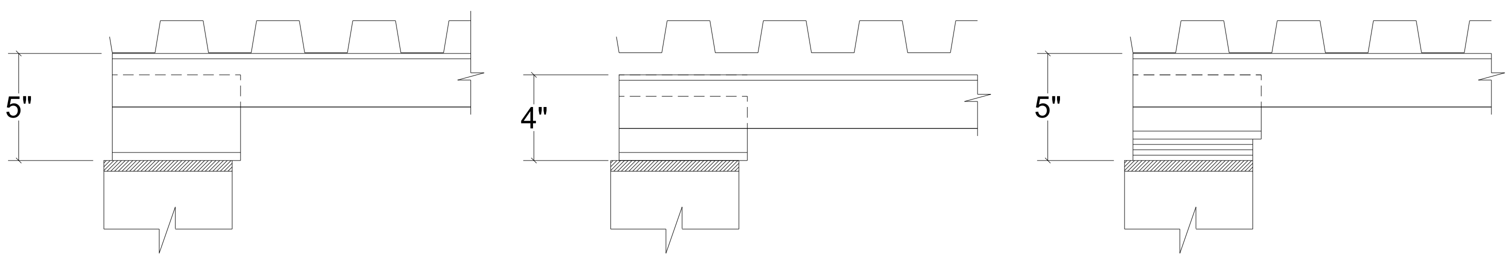
MANUF'D JOIST W/ STD. CAMBER
PRIOR TO INSTALLATION



JOIST AFTER INSTALLATION
WITH DEAD LOADS APPLIED

Reinforcing / Replacing / Adding

Bearing Seat Depth – Specify a shallower seat depth and then shim to raise top chord to deck.



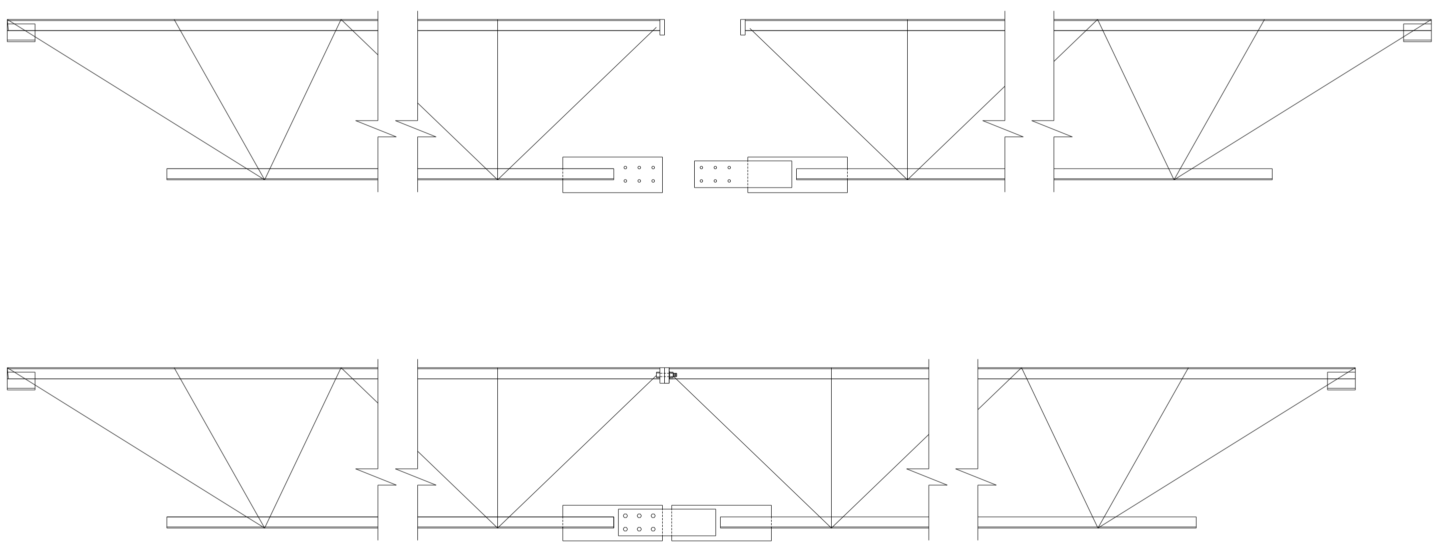
INSTALLED BEARING SEAT FOR EXISTING JOIST

NEW JOIST W/ SHALLOWER BEARING SEAT PRIOR

NEW JOIST W/ SHALLOWER BEARING SEAT AND SHIMMS

Reinforcing / Replacing / Adding

SPLICE – Using a joist w/ a field bolted splice allows each half of the joist set in place and then mated together.



JOIST w/ BOLTED SPLICE

Field Repairs

Poor field workmanship is a concern

Field Repairs

Field workmanship can weaken the joist

Field Repairs General Notes

- No modification that affects the strength of a steel joist or steel Joist Girder shall be made without the approval of the project structural engineer of record. See OSHA 29 CFR 1926.757 (7).
- THE DETAILS USED HEREIN WERE TAKEN FROM THE TYPICAL DETAILS PROVIDED IN SJI TECHNICAL DIGEST NO. 12 AND REQUIRE VERIFICATION AND APPROVAL BY THE PROJECT STRUCTURAL ENGINEER OF RECORD.
- All repairs shall be done in a professional and quality manner. Workman preforming repair are responsible for the workmanship of the repair.

Field Repairs General Notes

- All Steel shall be a minimum yield of FY = 50 ksi, unless noted otherwise.

- All welding shall be performed by a welder qualified to the current AWS requirements. Welder shall be qualified for the welding procedures and positions required to properly install the reinforcing.

- All welds are to be made using E70xx electrodes. Weld requirements are as specified in the details above.

- Repairs shall be inspected by an AWS certified weld inspector.

Field Repairs Procedures

Example:

1. Measure and cut reinforcing angle to proper length to fit connection details.

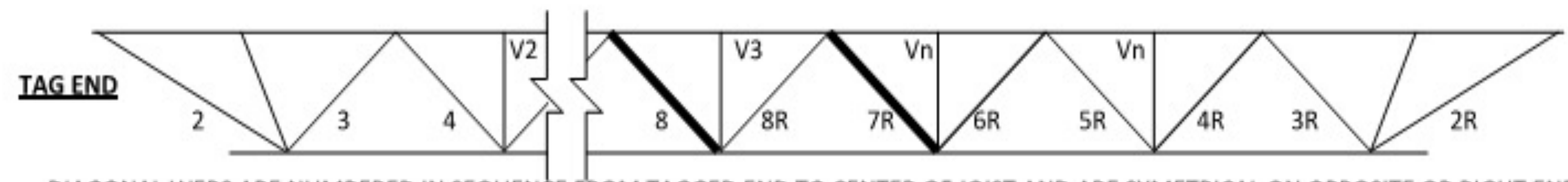
2. Place new reinforcing angles on side(s) of damaged web. Use 2-L2x2x0.25. Weld per Detail 3

3. Weld reinforcing angle to top chord angles in accordance with Detail 2.

4. Remove existing web without damaging joist top and bottom chord angles.

Field Repairs Sketches

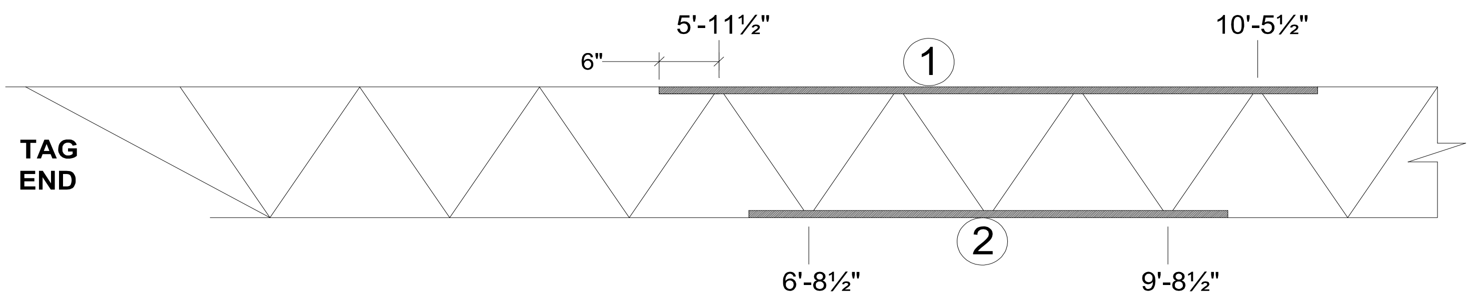
Show the locations on the joist where the repairs are needed.



DIAGONAL WEBS ARE NUMBERED IN SEQUENCE FROM TAGGED END TO CENTER OF JOIST AND ARE SYMETRICAL ON OPPOSITE OR RIGHT END WITH "R" DESIGNATION. VERTICAL WEBS NUMBERED IN SEQUENCE AS Vn FROM THE TAGGED END TO THE OPPOSITE END.

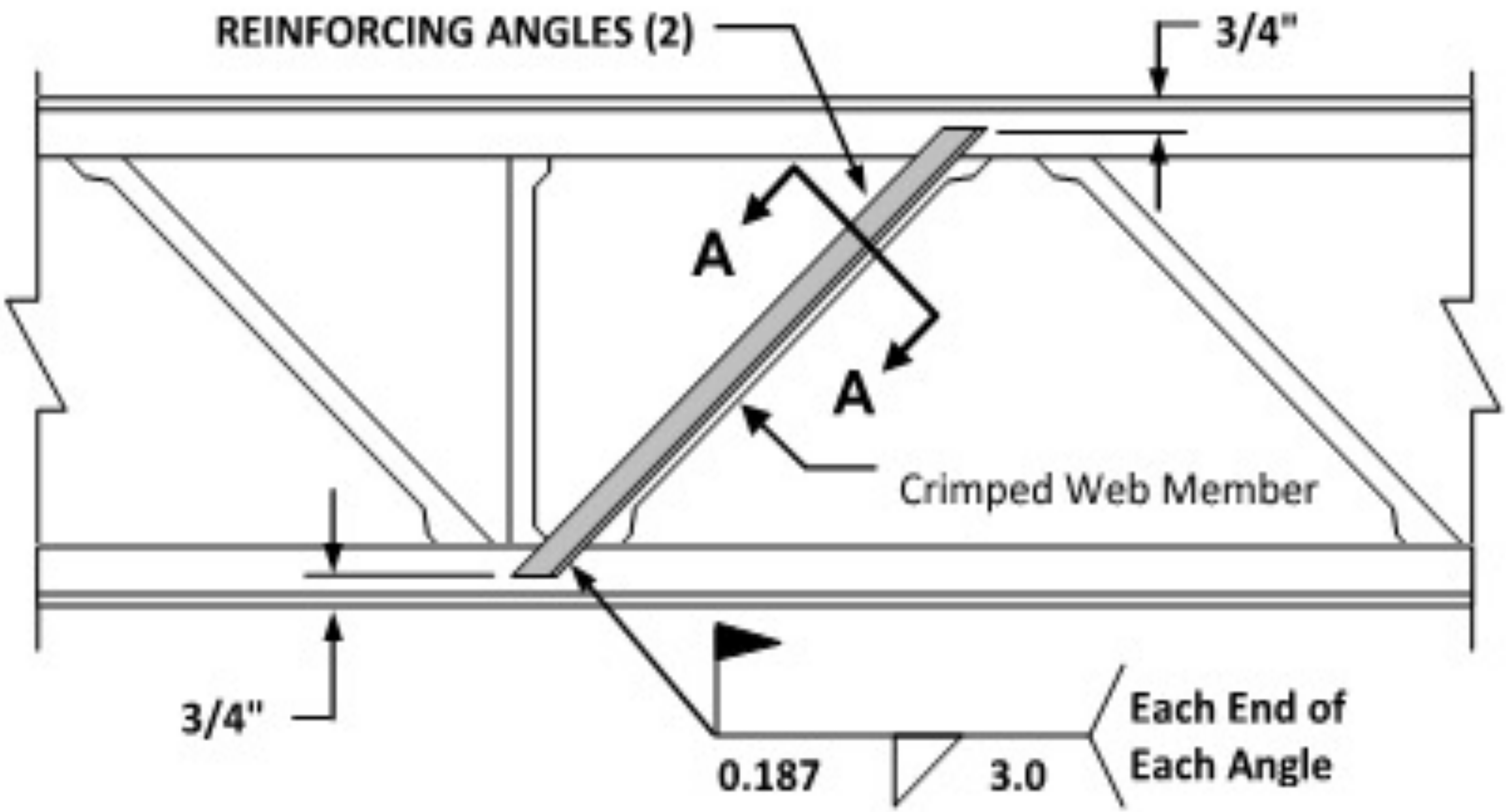
(1) ADD 2 - ¾"x5'-6" RODS TO TOP CHORD. WELD PER DETAIL 1A

(2) ADD 2 - ¾"x4'-0" RODS TO BOTTOM CHORD. WELD PER DETAIL 2.

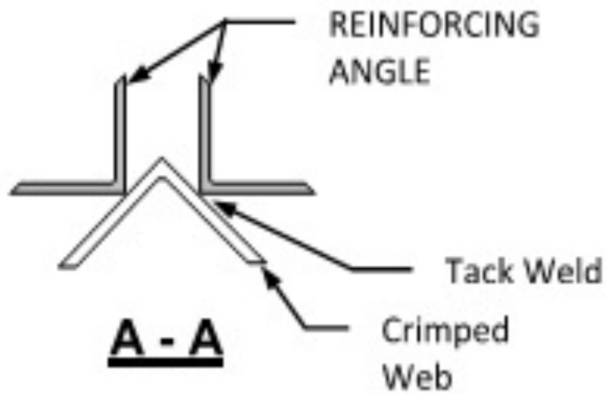


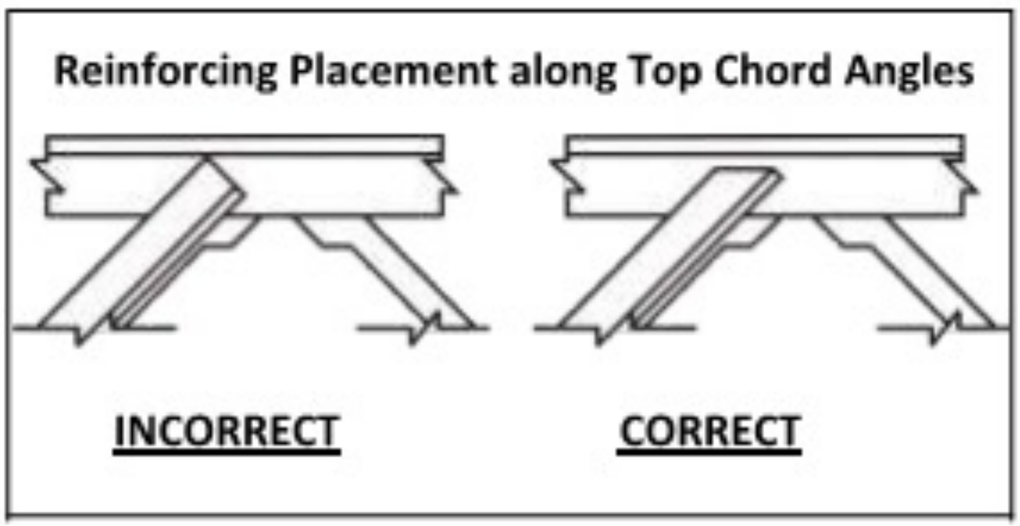
Field Repairs Sketches

Provide details showing the information needed make the individual joist member repairs.



Field Repairs Sketches





Chapter 3: Design Approaches for Strengthening Joists

Two Design Approaches to Reinforce Individual Joist Members

- Approach I
  - Ignore the existing member strength.
  - Simply design the reinforcing members to carry the total load.
- Approach II
  - Use the existing member strength.
  - Must be able to determine the existing member forces. (i.e., in-place dead load joist analysis)

Design Approaches for Strengthening Individual Joist Members

Considerations for Either Approach

- Cost of reinforcement materials is insignificant relative to the cost of labor.
- Safest to reinforce the joist in the shored position
  - Welding can generate enough heat to cause temporary loss of steel strength.
  - Transverse field welds should be avoided.
- Best to reinforce the members with dead and live loads removed
  - Jack the joist up to a calculated deflection
- Pay close attention to eccentricities caused by the reinforcing.

Design Approaches for Strengthening Individual Joist Members

For Approach II

- It is assumed that applied forces are distributed between the existing member and the reinforcing member in direct proportion to their areas.
- If joists are shored to remove existing load, the preload is then zero.
- If joists are not shored, preload can be calculated based on load(s) present at the time of reinforcing.
- Shoring and jack placement is the responsibility of the Specifying Professional.

Design of Reinforcing for Tension Members (Approach II)

1. Determine the total area, A_{tr}, for the reinforced member

$$A_{tr} = \frac{(P_t - P_p)}{(P_o - P_p)} A_e$$

SJI Technical Digest #12, Eq. 3-2

- Where,
  - A_{tr} = Total area required (existing member and required reinforcing), in^2
  - A_e = Area of existing member, in^2
  - P_0 = Original force for the existing member (original design force), kips.
  - P_p = Preload in the existing member at the time of reinforcing, kips.
  - P_t = Required strength, kips.
- Assumes existing steel and reinforcing steel have equal yield strength.

Design of Reinforcing for Tension Members (Approach II)

- Design procedures when the yield strengths of the two materials are not equal
- Assume both materials have the same yield strength as that of the lowest material used
  - Most conservative method
- Use the actual yield strength of each material in the design
  - Allow each material to achieve the full allowed stress level

Design of Reinforcing for Tension Members (Approach II)

2. Determine required area of reinforcing, A_r

$$A_r = A_{tr} - A_e$$

3. The force in the reinforcing member equals

$$P_r = \left(\frac{A_{fr}}{A_t}\right)\left(P_t - P_p\right)$$

- Where,
  - A_{fr} = Area of the furnished reinforcing, in^2
  - A_t = Area of existing member plus the area of the furnished reinforcing, in^2

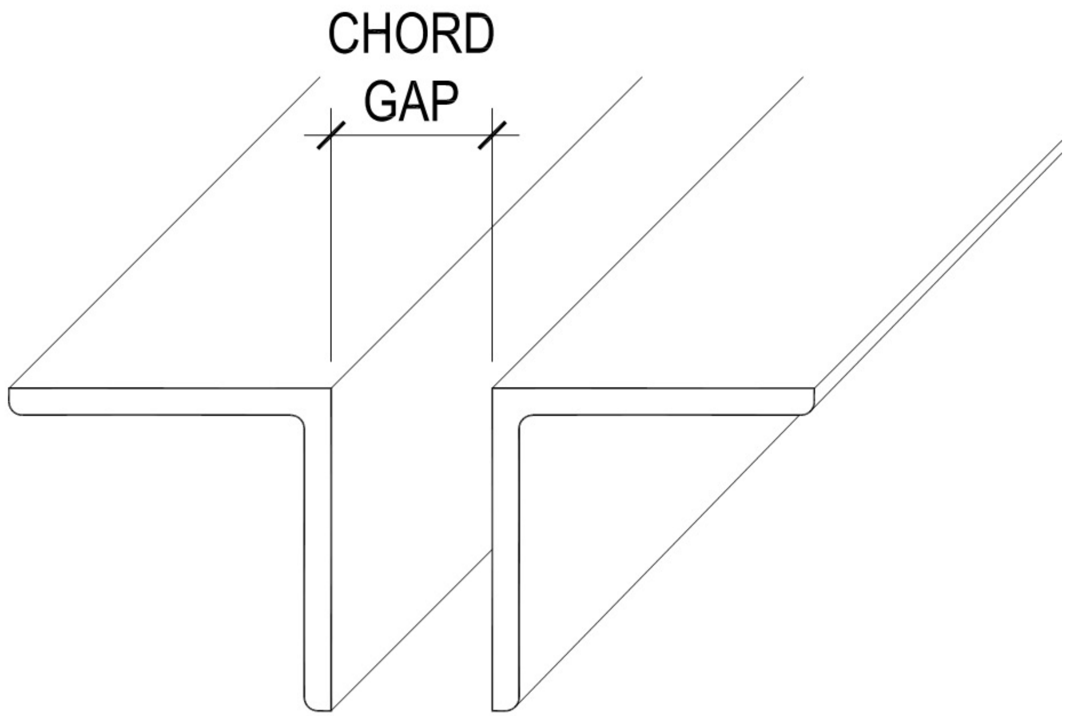
Design of Reinforcing for Compression Members (Approach II)

1. Select a trial reinforcing member.
2. Check the buckling strength of the composite member.
   - If a preload force exists, determine the magnitude of the compressive stress, f_p, in the existing member due to the preload.
   - F_{ye} = minimum yield stress of existing member, ksi
   - For the buckling check, use F_y as the minimum of

     $(F_{ye} - f_p)$ or F_y
3. Design the weld for the reinforcing member. The force in the weld is

$$P_{rw} = \left(\frac{A_{fr}}{A_t}\right)\left(P_t - P_p\right)$$

Type of Chord Members



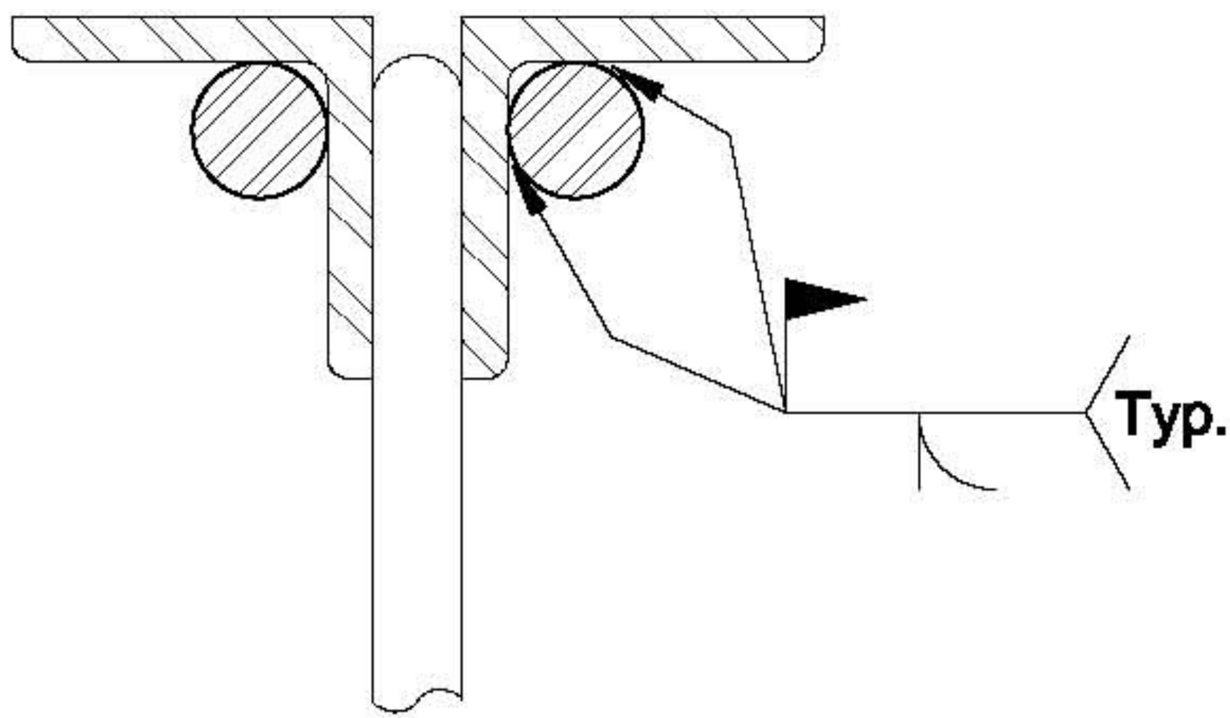
Chord Reinforcement

Typical reinforcement details

- Top chord
  - More difficult to reinforce since the floor or roof deck is usually in place.
  - Overhead welds may be required.
- Bottom chord
  - Easier to access.
  - No overhead welds required.

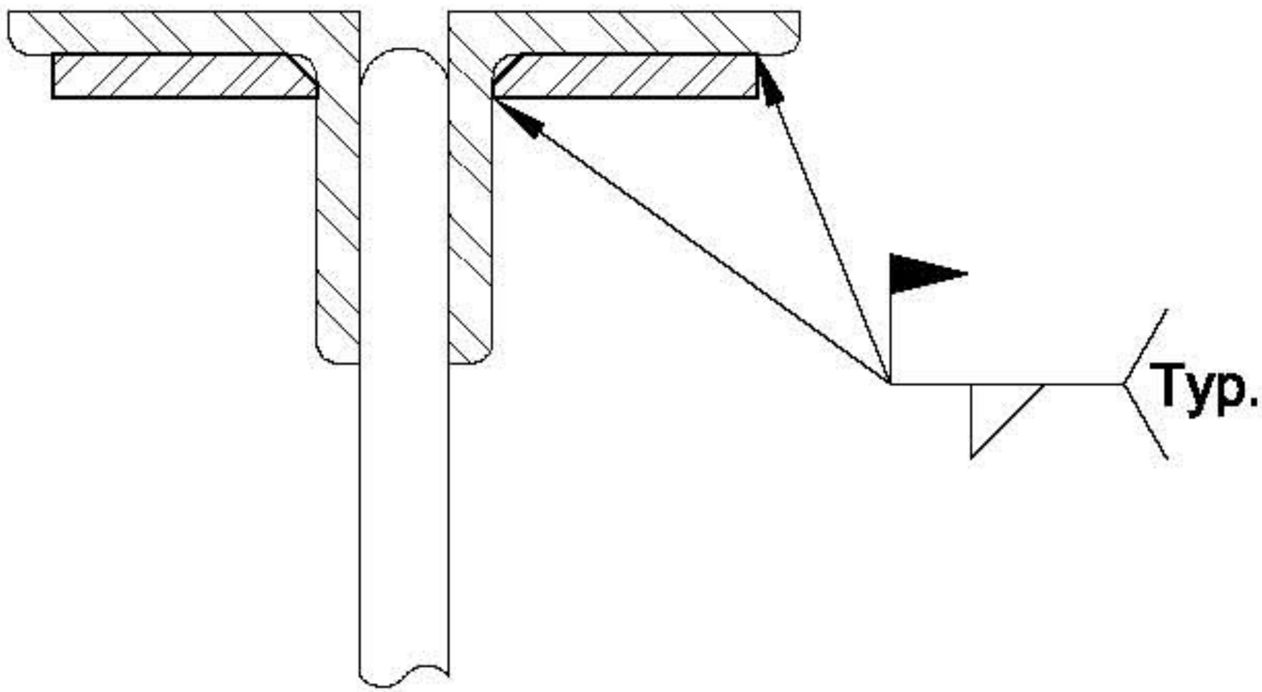
Chord Reinforcement

Top Chord Reinforcement – Rods



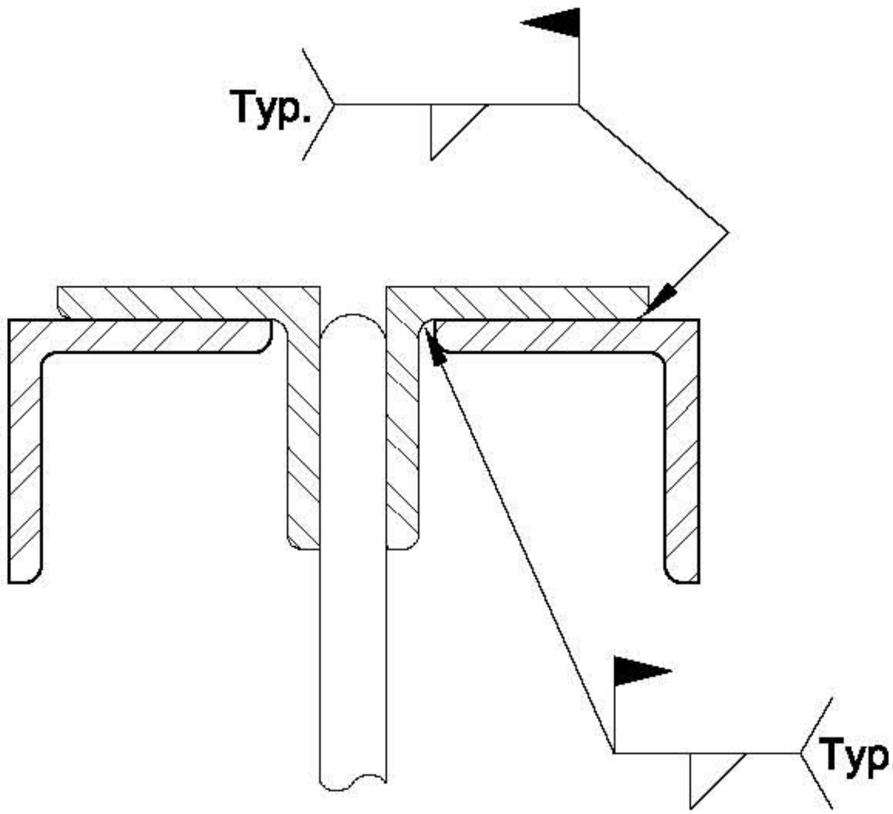
Chord Reinforcement

Top Chord Reinforcement – Plates



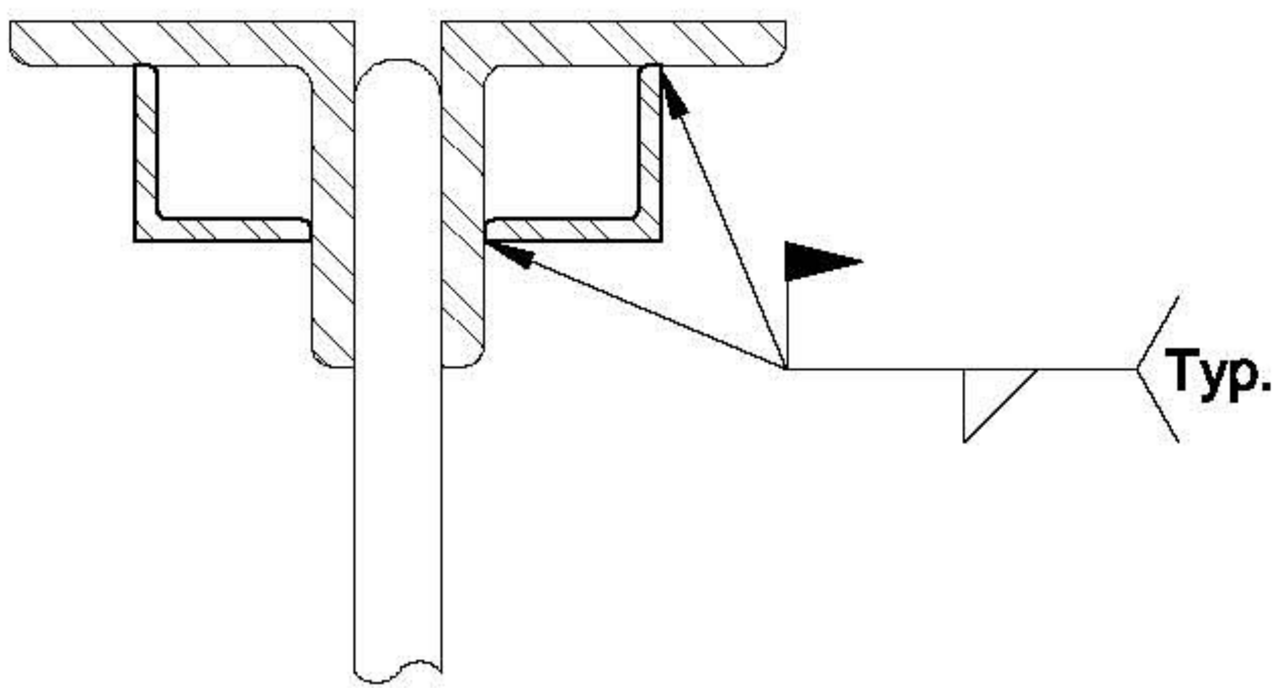
Chord Reinforcement

Top Chord Reinforcement – Angles



Chord Reinforcement

Top Chord Reinforcement – Angles

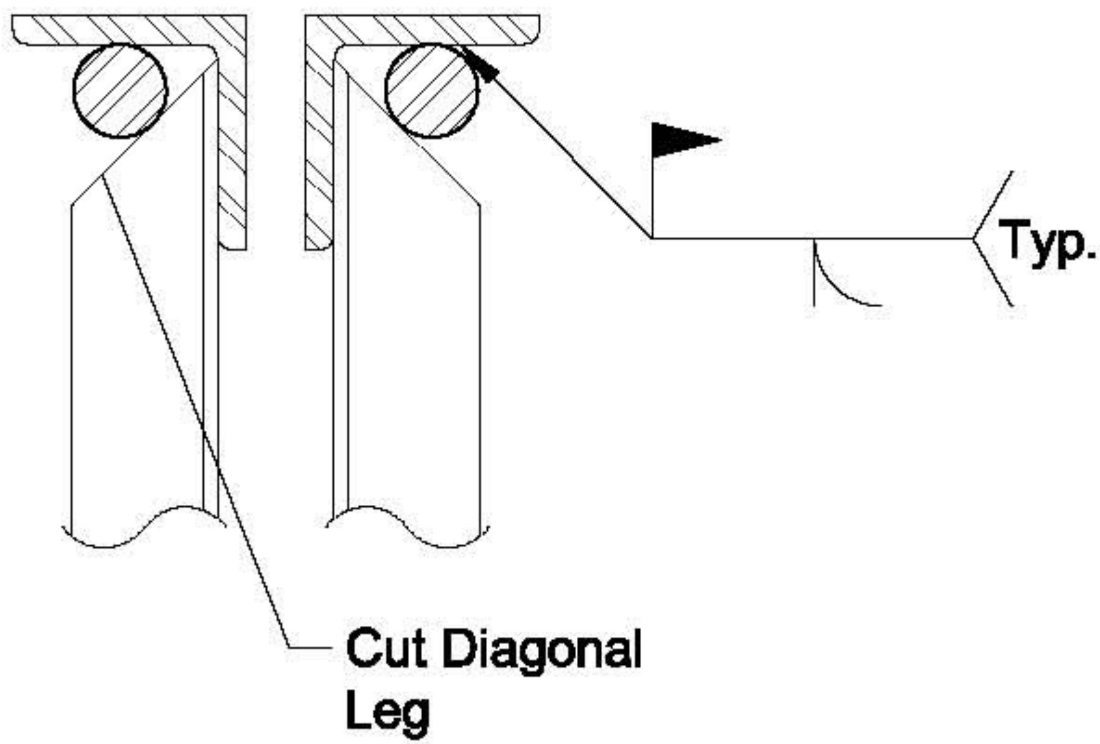


Chord Reinforcement

Angle Interference with Top Chord Reinforcement

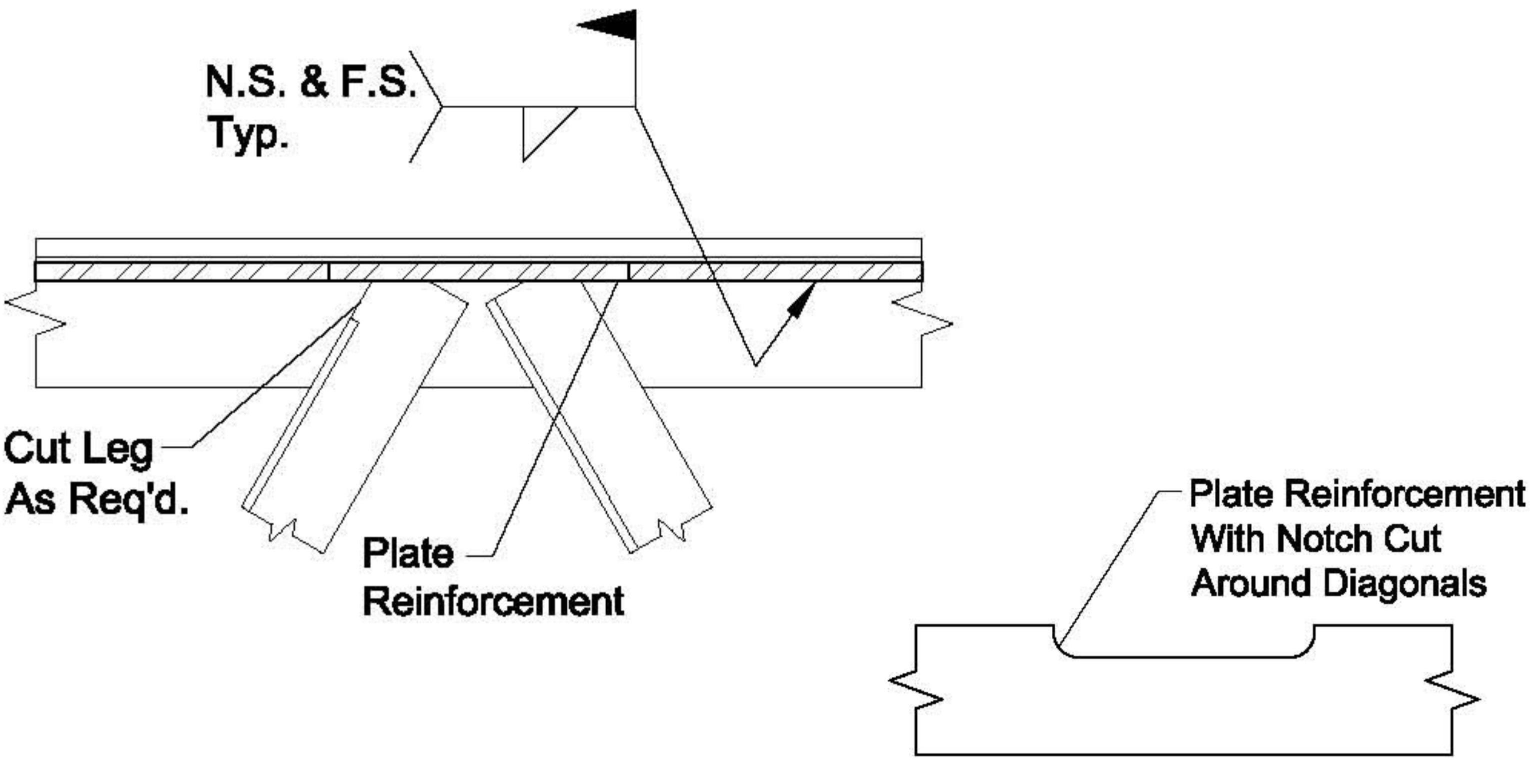
Chord Reinforcement

Top Chord Reinforcement – Rods



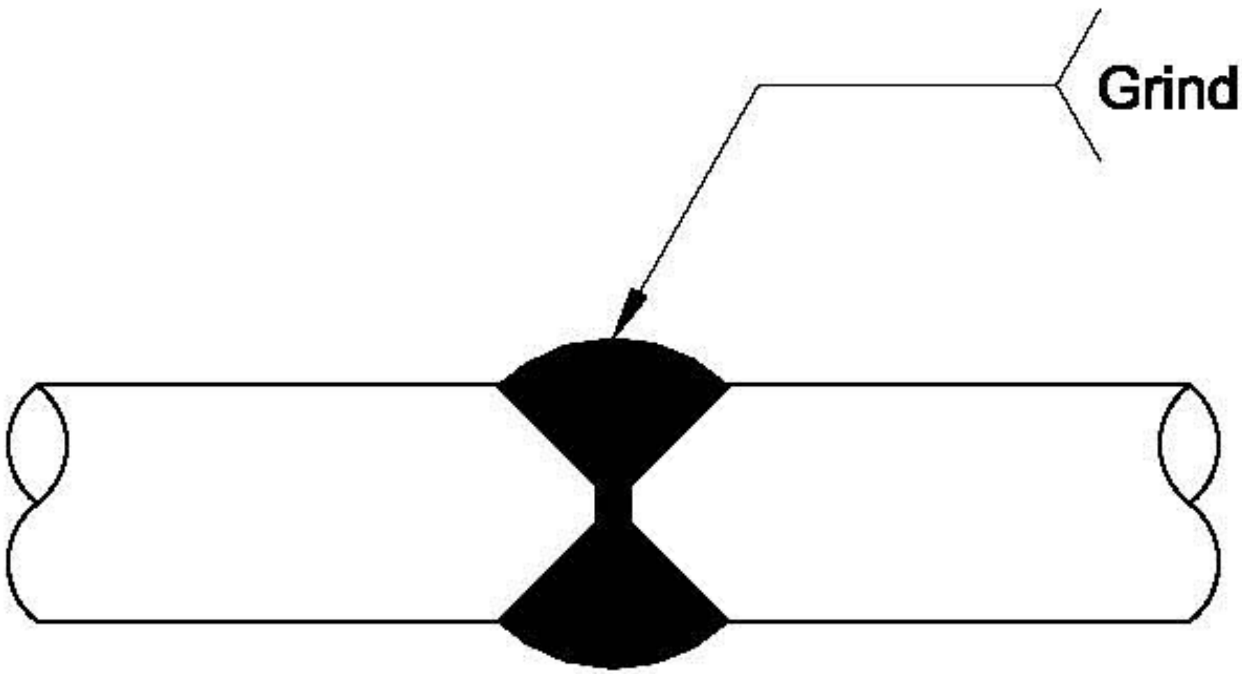
Chord Reinforcement

Top Chord Reinforcement Requiring Notch



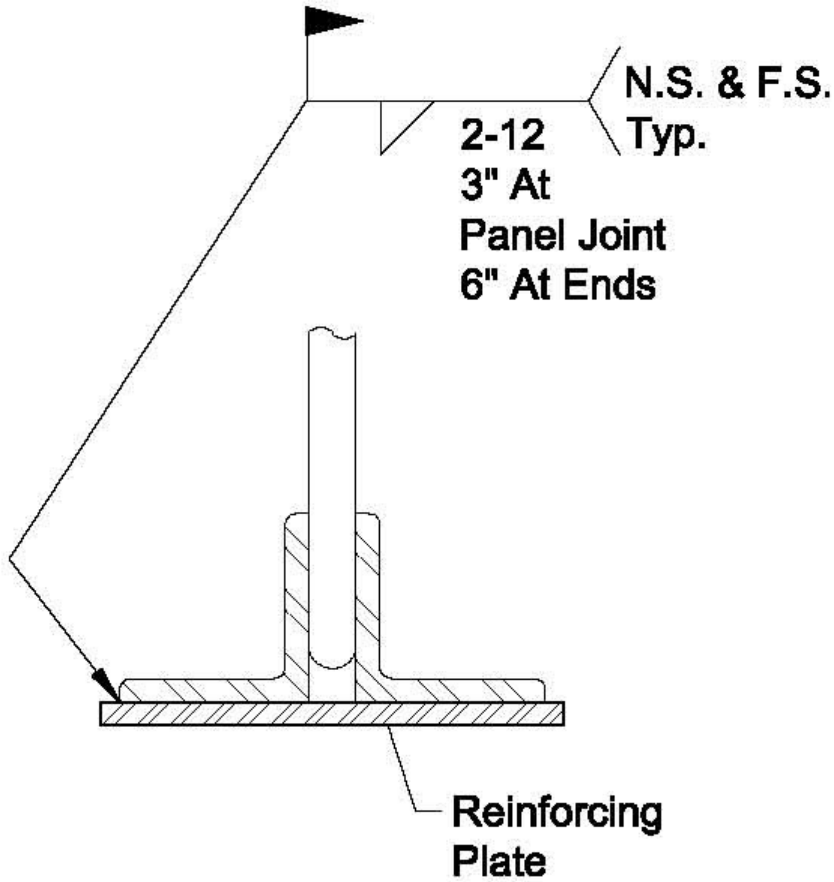
Chord Reinforcement

Rod Splice



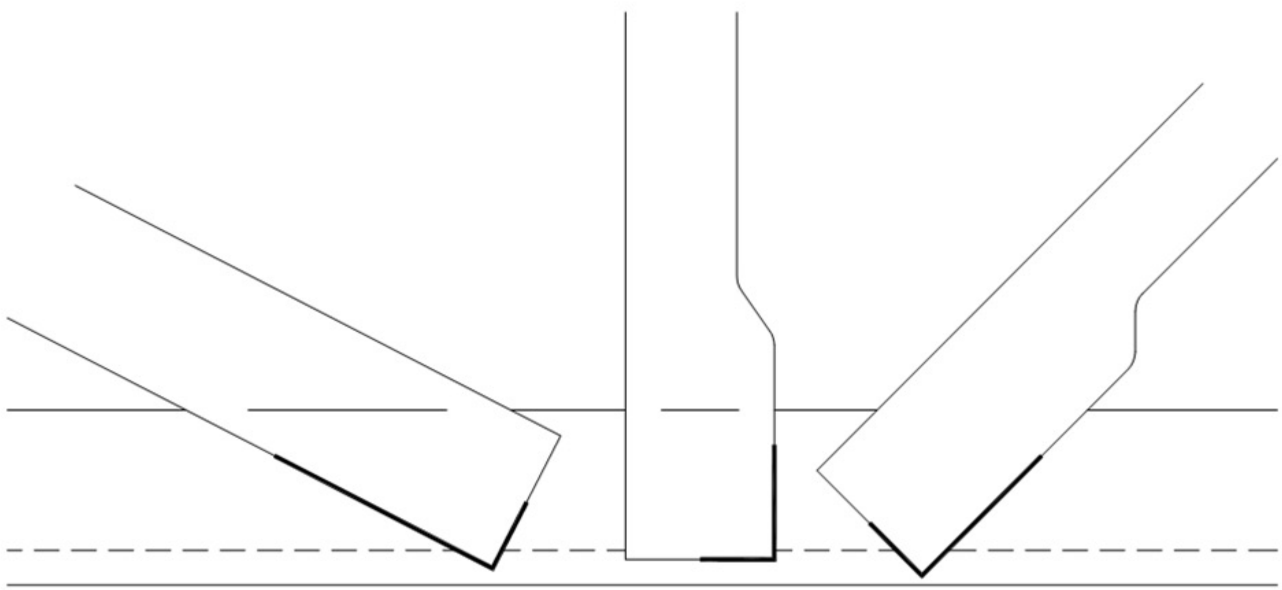
Chord Reinforcement

Bottom Chord Reinforcement



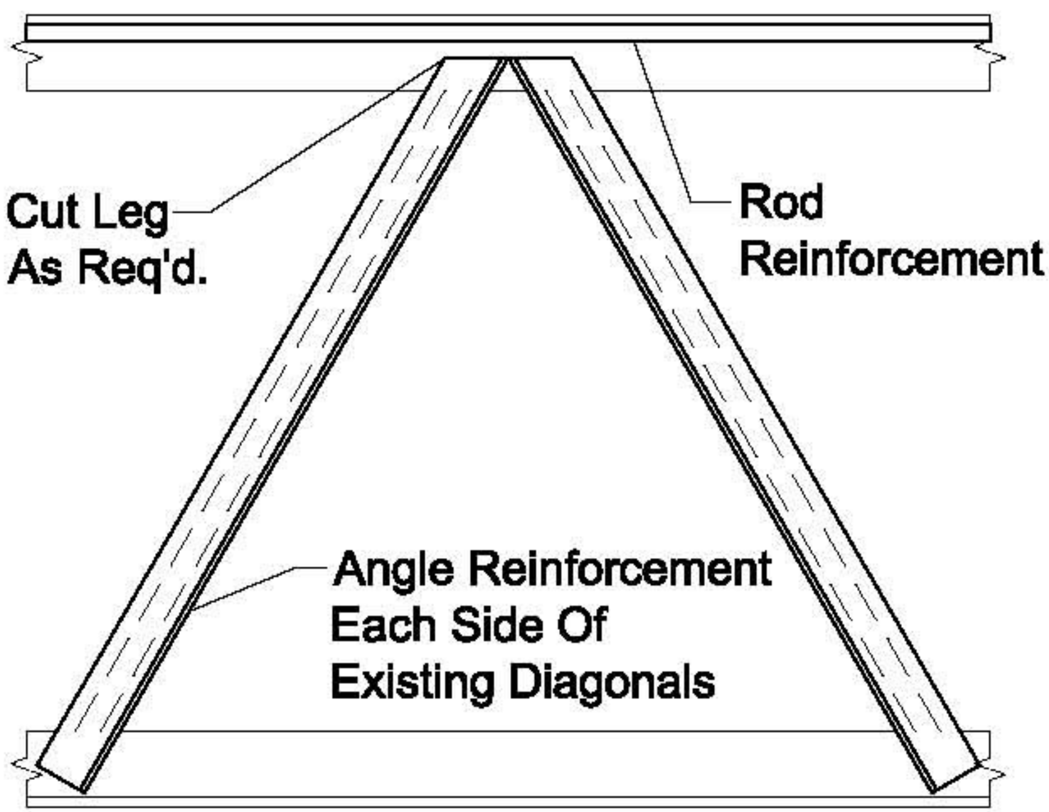
Web Weld Location

The typical location for the manufacturer's weld for double angle and crimped angle webs



Rod Web Reinforcement

Angle Reinforcement on Rod Web Joist



Rod Web Reinforcement

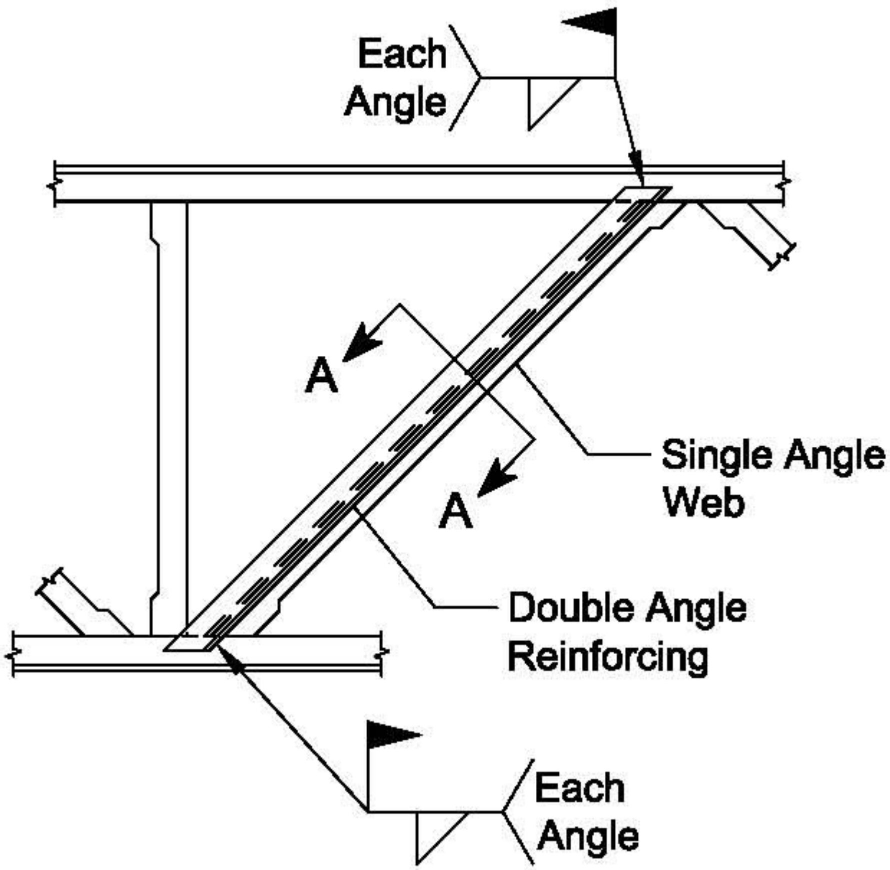
Angle Reinforcement on Rod Web Joist

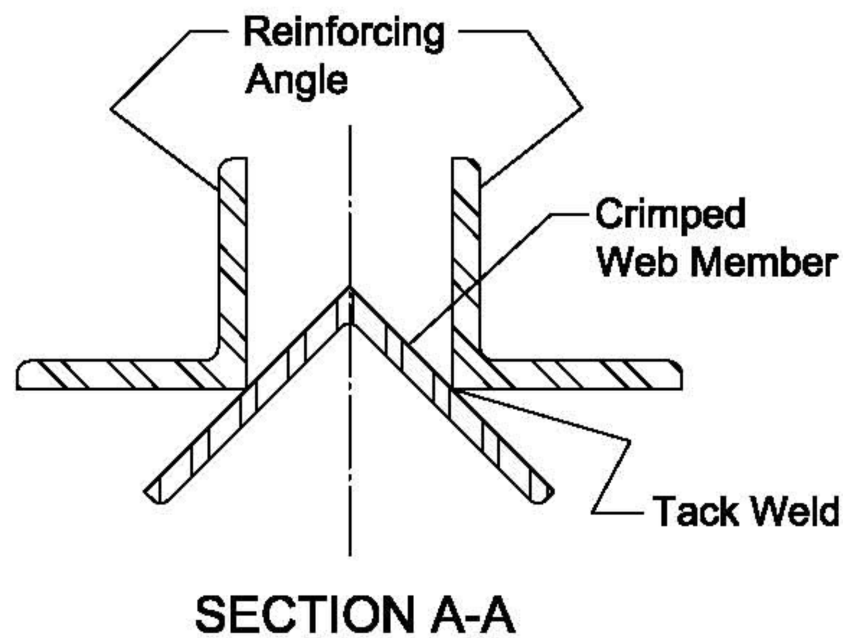
Crimped Web Reinforcement

Joist with Crimped Web Members

Crimped Web Reinforcement

Angle Reinforcement on Crimped Web Joist



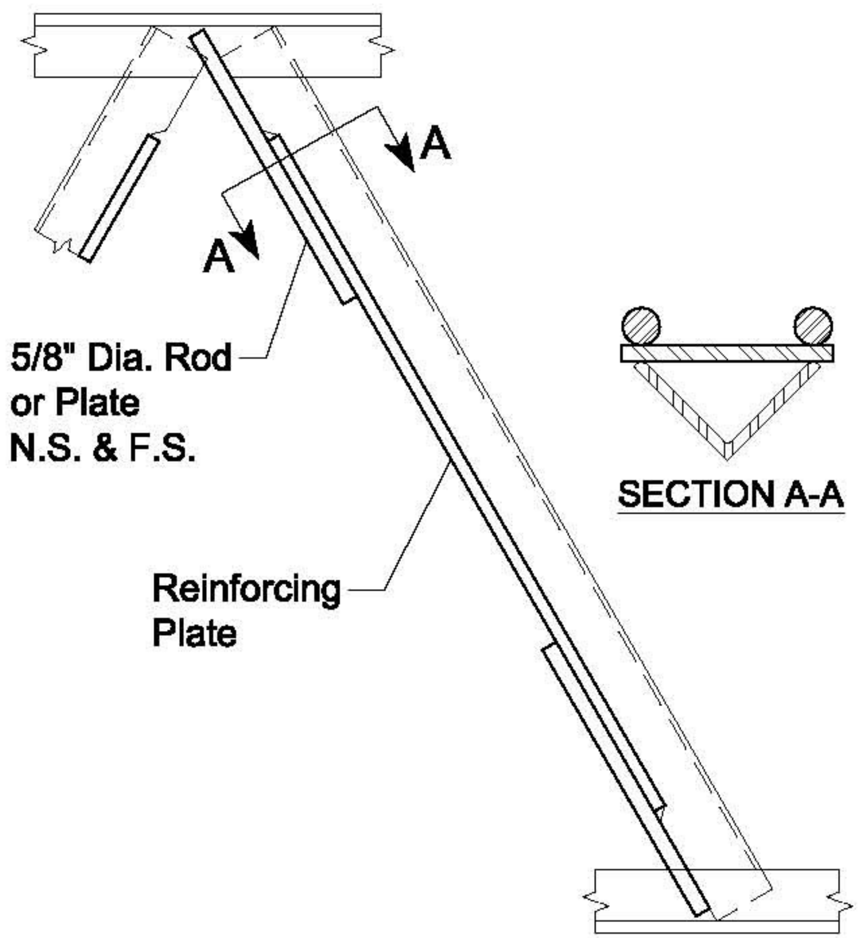


Crimped Web Reinforcement

Angle Reinforcement on Crimped Web Joist

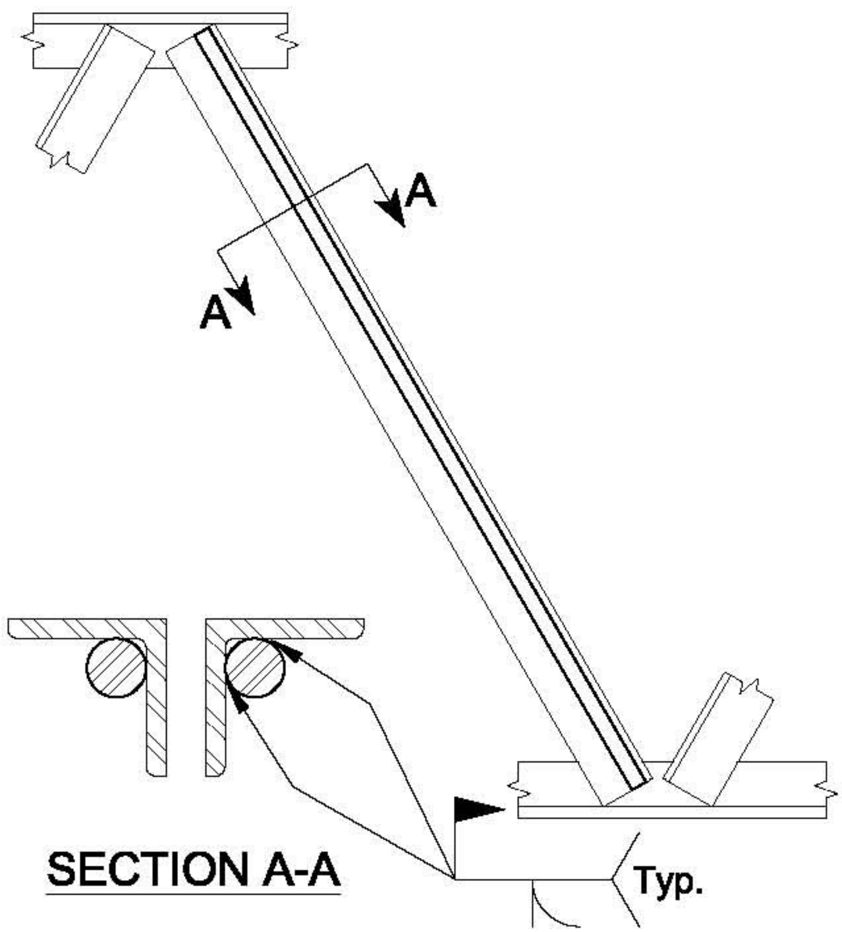
Crimped Web Reinforcement

Crimped Web Reinforcement



Double Angle Web Reinforcement

Angle Web Reinforcement with Rod

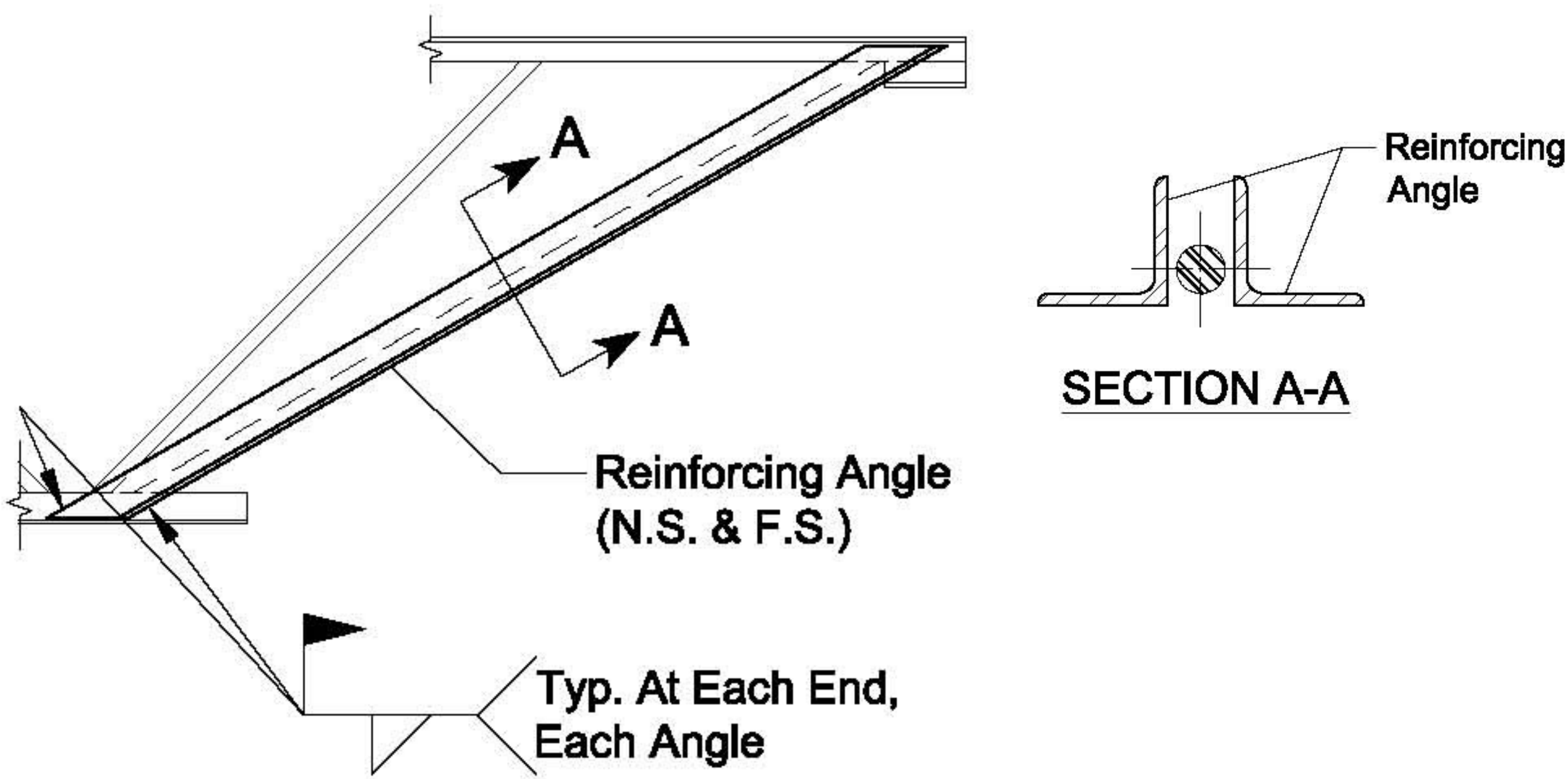


Double Angle Web Reinforcement

Angle Web Reinforcement with Rod

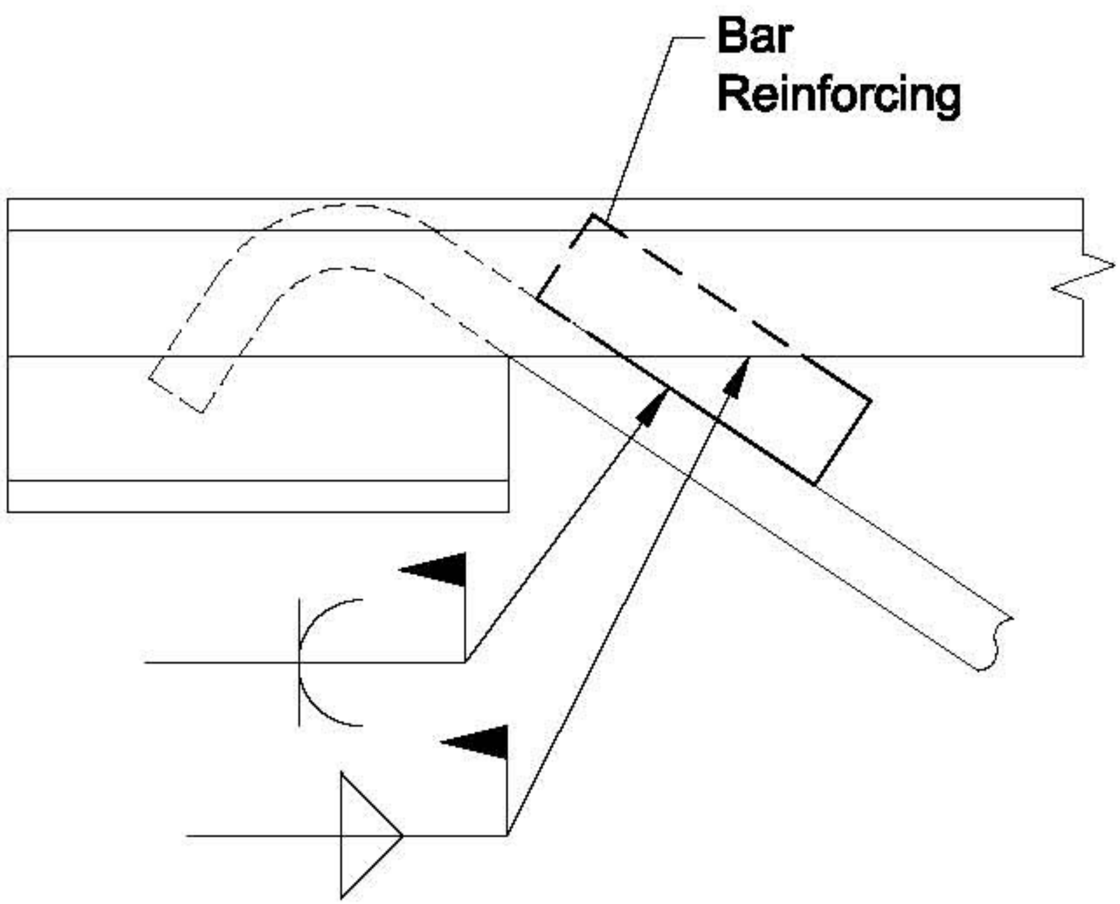
End Diagonal Web Reinforcement

End Diagonal Reinforcement with Angle



End Diagonal Web Reinforcement

Bar Added for Additional Weld on End Diagonal



Polling Question #1

When evaluating whether a joist should be repaired or replaced the following should be considered:

A) Skill of workman

B) Effectiveness of repair

C) Cost

D) All of the above

Design Examples for Strengthening Joists

Example 3.1	Strengthening a joist seat with plate
Example 3.2	Strengthening a joist with crimped angle webs
Example 3.3	Strengthening a joist with rod webs
Example 3.4	Strengthening an end diagonal using double angles
Example 3.5	Joist girder chords
Example 3.6	Strengthen a joist with double angle webs
Example 3.7	Design of a strut to prevent bending

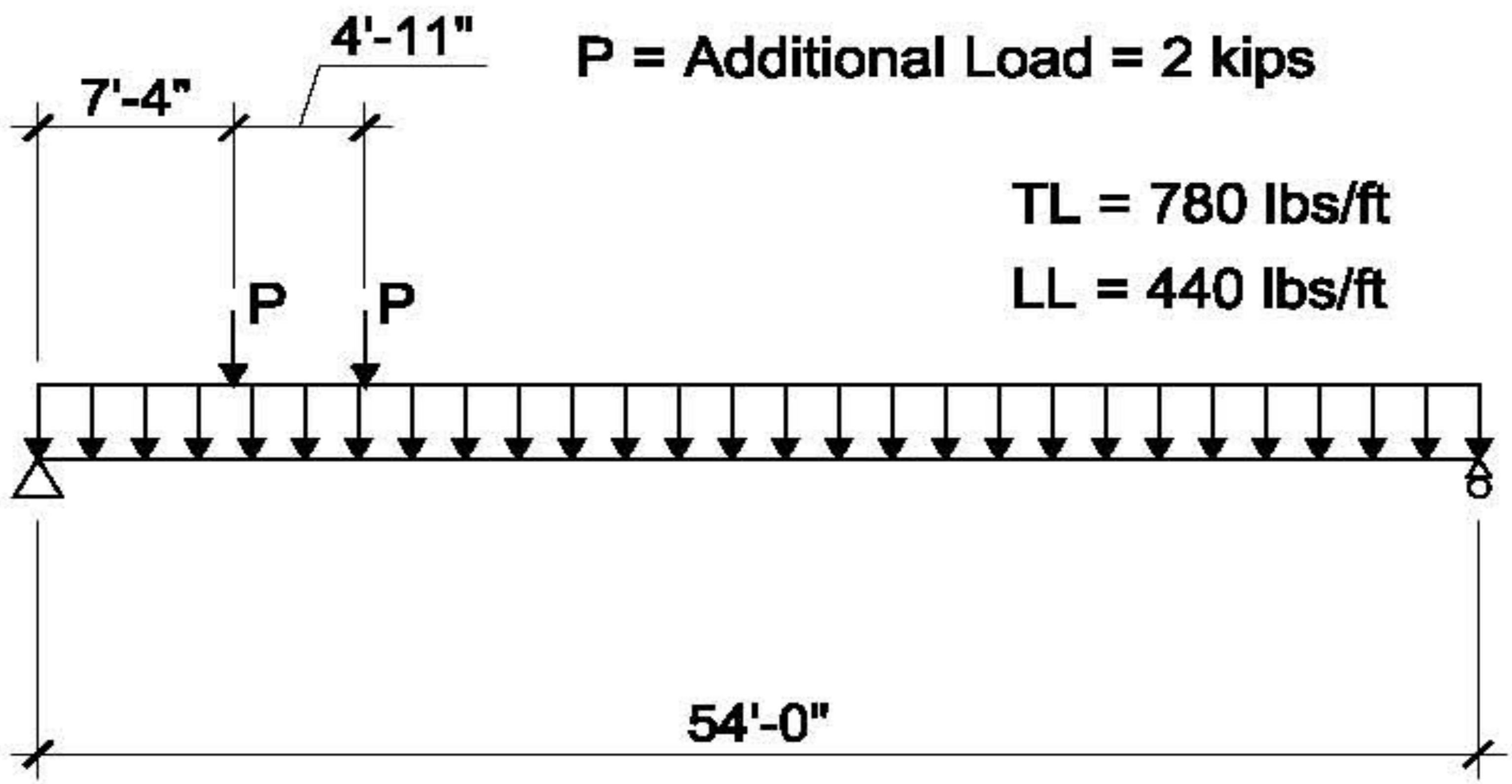
Example 3.6 Strengthening of a Joist with Double Angle Webs

Given Conditions

- A remodel requires that additional equipment be installed and supported by the joists
- Original joists were designated as 32LH780/440
- Added equipment will be centered over two joists
  - Resulting load is 2000 lbs located at 7'-4" and 12'-3" from the tag end of the joist
- Uniform loads in the designation are the uniform design loads required
  - Load redistribution method not a feasible solution

Example 3.6 Strengthening of a Joist with Double Angle Webs

32LH780/440 with Additional Concentrated Loads



Example 3.6 Strengthening of a Joist with Double Angle Webs

Analysis

- Overstressed webs are double angles
- Axial force in the end web member (W2)
  - Required force = 60.5 kips
  - Allowable force (from manufacturer) = 56.3 kips
- First compression web member (W3)
  - Required force = 18.1 kips
  - Allowable force (from manufacturer) = 17.2 kips
- Originally designed using Allowable Stress Design
  - Use (ASD) for reinforcement also
- Approach II will be used.

Example 3.6 Strengthening of a Joist with Double Angle Webs

End Web Reinforcing

Load in end tension web (W2) at time of reinforcing is 23.0 kips

Total area required =

$$A_{tr} = \frac{\left(P_t - P_p\right)}{\left(P_o - P_p\right)} A_e$$

Where:

P_t = 60.5 kips (required force)
P_p = 23.0 kips (preload force)
P_o = 56.3 kips (original allowable design force)
A_e = 1.876 in.^{2} (area of two 2 x 2 x 0.250 angles)

Thus,

$$A_{tr} = \frac{\left(60.5 - 23.0\right)}{\left(56.3 - 23.0\right)} \left(1.876\right) = 2.113\ in.^2$$

Example 3.6 Strengthening of a Joist with Double Angle Webs

The required area of reinforcing = $A_r = A_{tr} - A_e = 2.113 - 1.876 = 0.237\ in.^2$

Add round rods for reinforcement: Two ¾" diameter rods placed in heel of angles

Area of furnished reinforcing,

$$A_{fr} = \frac{2\pi d^2}{4} = \frac{2\pi(0.75)^2}{4} = 0.884\ in.^2$$

> 0.237 in² Therefore, OK

The total area, At, is the sum of the areas of the existing web angles plus the areas of the reinforcing rods,

$$A_t = A_e + A_{fr} = 1.876 + 0.884 = 2.760\ in.^2$$

Example 3.6 Strengthening of a Joist with Double Angle Webs

- The force in the reinforcing members equals

$$P_r = \left(\frac{A_{fr}}{A_t}\right)\left(P_t - P_p\right) = \left(\frac{0.884}{2.760}\right)\left(60.5 - 23.0\right) = 12.01\ kips$$

Check the stress in the round rod reinforcing member:

- F = P/A =12.01/0.884 = 13.59 ksi < 21.6 ksi

– Therefore, the use of A36 material is OK

Example 3.6 Strengthening of a Joist with Double Angle Webs

End Web Reinforcing Weld Design

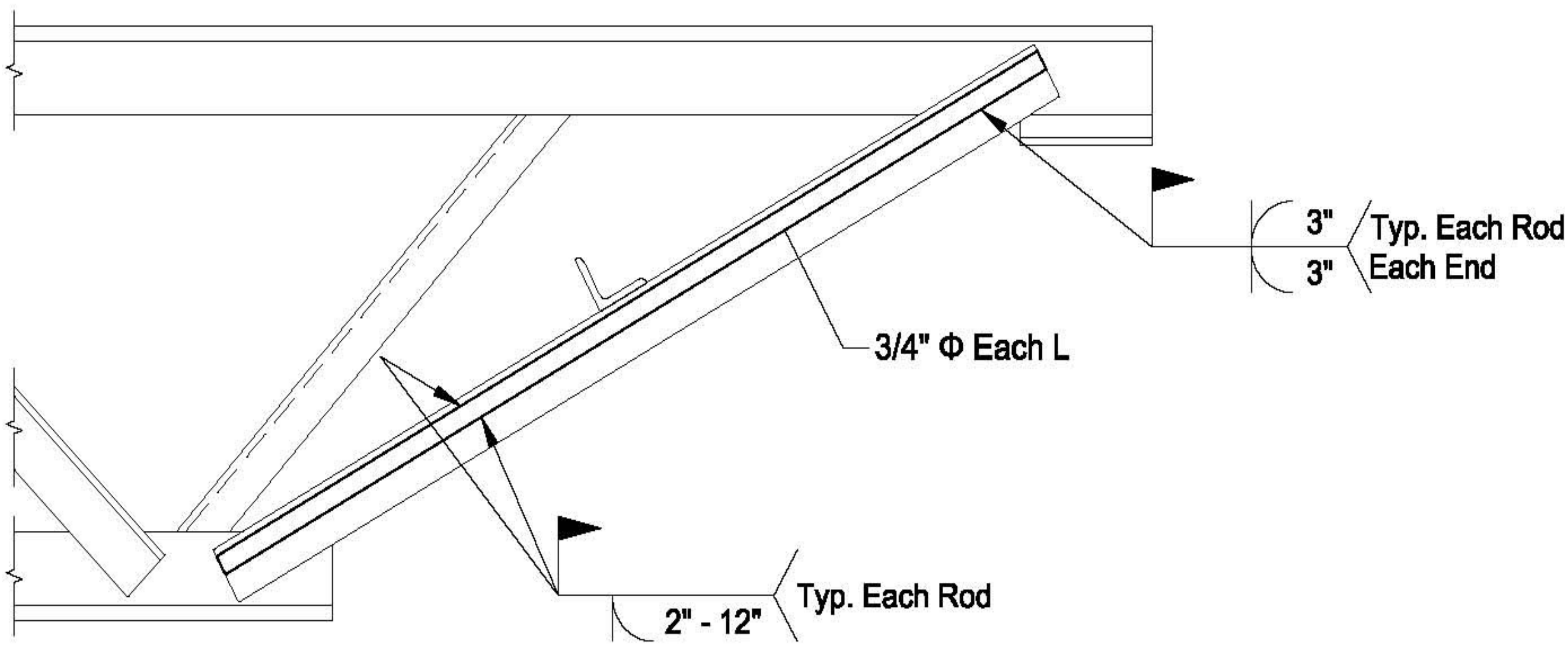
- Joint between Rod and Angle will be a partial-joint-penetration flare bevel groove weld.
- Effective throat thickness is 5/16 times the rod radius.
  - (AISC Specification Table J2.2 for Flare Bevel Groove weld)
- Effective throat = ((5/16 x (3/4”/2)) = 0.117 in.

Example 3.6 Strengthening of a Joist with Double Angle Webs

- Allowable shear per weld using E70 electrodes from AISC Table J2.5, Available Strength of Welded Joints is 2.46 kips/in.
- The total length of weld required to develop the force in each rod =12.01 / 2.46 = 4.88 in.
- The 6 in. of weld shown in the following figure, at the ends of each reinforcing rod, is more than adequate.

Example 3.6 Strengthening of a Joist with Double Angle Webs

Reinforcing End Diagonals



Example 3.6 Strengthening of a Joist with Double Angle Webs

End Web Weld Design for Total Required Force

- Pt = 60.5 kips
- Based on 3/16” fillet weld and using E70 electrodes, the allowable shear per inch of weld equals:

  (0.707)(0.188 in.)(21 ksi) = 2.79 kips/in.

- Thus, 60.5/2.79 = 21.7 in.

  (use 11 in. at each end of each web angle)

The weld for the existing web member should be checked to ensure that is 11” long.

Example 3.6 Strengthening of a Joist with Double Angle Webs

Check for Tensile Rupture

Conservatively, U can be taken as 0.6 or can be determined from AISC Specification Table D3.1, Shear Lag Factors for Connections to Tension Members.

When Case 2 is selected,

$$U = 1 - \frac{\bar{x}}{\ell} \qquad Case\ 2$$

U depends on the weld arrangement. AISC does not address the condition of unequal weld lengths on the heel and toe of the angle so use the length along the heel.

Assume that 4 in. of weld is placed on the heel, 7 in. along the toe.

Example 3.6 Strengthening of a Joist with Double Angle Webs

Check for Tensile Rupture

Where: $\bar{X}$ is the centroid location for the composite section comprised of web angle plus the round rod

l is the length of the connection

$$\bar{X} = (0.25 + 0.375) = 0.625 in.$$

$$l = 4 in.$$

$$U = 1 - \frac{0.625}{4} = 0.844$$

Example 3.6 Strengthening of a Joist with Double Angle Webs

The nominal strength P_n based on tensile rupture equals $F_u A_e$ or $U F_u A_t$

- Fu = 65 ksi since the weld is placed on the angle

$$P_n = U F_u A_t = (0.844)(65)(2.760) = 151.4\ kips$$

$$P_{available} = \frac{P_n}{\Omega_t} = \frac{151.4}{2.00} = 75.71\ kips$$ > 60.5 kips Therefore, OK

Example 3.6 Strengthening of a Joist with Double Angle Webs

First Compression Web Reinforcing

Design Approach II:

1. Select a trial reinforcing member.
2. Check the buckling strength of the composite member.
   a. Determine the magnitude of the compressive stress in the existing member due to the preload, f_p
   b. F_{ye} = minimum yield stress of existing member, ksi
   c. For the buckling check, use F_y as the minimum of

      $(F_{ye} - f_p)$ or F_y
3. Design the weld for the reinforcing member. The force in the weld is

$$P_{rw} = \left(\frac{A_{fr}}{A_t}\right)\left(P_t - P_p\right)$$

Example 3.6 Strengthening of a Joist with Double Angle Webs

The req'd load in the first compression web (W3) is 18.1 kips

Existing member = 2 – L1.5x1.5x0.138

Preload = P_p = 6.9 kips (from existing load analysis)

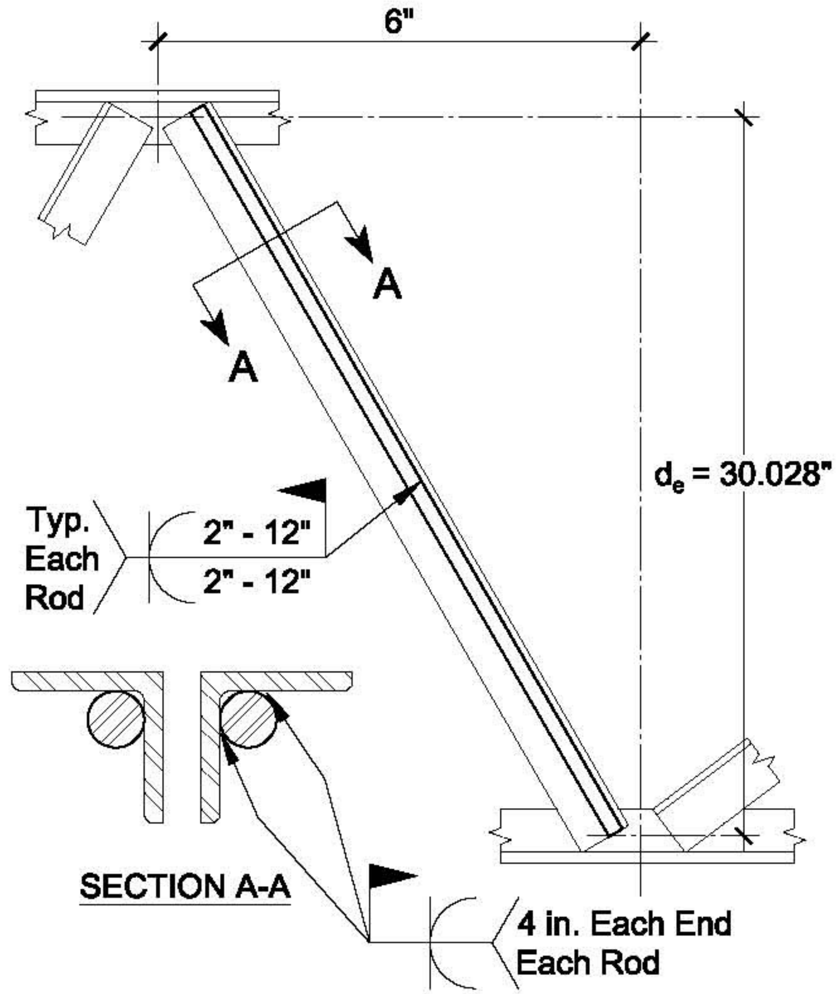
Try 2- ¾" diameter rods, F_y = 36 ksi for reinforcement

Determine the section properties for web angles, rods, and combined section.

1 - L1.5x1.5x0.138	1 - ¾" Rod	Combined 2-L & 2 rods
$A_e = 0.395$ in.^{2}	$A_{fr} = 0.442$ in.^{2}	$A_t = 1.674$ in.^{2}
$r_x = 0.463$ in.	$r = 0.188$ in.	$r_t = 0.350$ in.

Example 3.6 Strengthening of a Joist with Double Angle Webs

Double Angle Reinforcing with Rod



Example 3.6 Strengthening of a Joist with Double Angle Webs

Check buckling strength of the composite section

For compression webs, the allowable load is determined using AISC Specification Chapter E.

$$P_c = F_a A_t$$

Where,

P_c is the allowable compressive strength, P_n / Ω_c , kips

F_a is the allowable compressive stress, F_{cr} / Ω_c , ksi

A_t is the composite member cross-sectional area, in.^{2}

Safety factor, $\Omega_c = 1.67$

Example 3.6 Strengthening of a Joist with Double Angle Webs

Check buckling strength of the composite section (cont'd)

Determine the yield stress to be used:

Preload, $P_p = 6.9$ kips

Stress in the existing web:

$$f_p = \frac{6.9}{(2)(0.395)} = 8.73\ ksi$$

Yield stress to be used is the minimum of:

$F_{ye} - f_p = 50 - 8.73 = 41.27$ ksi

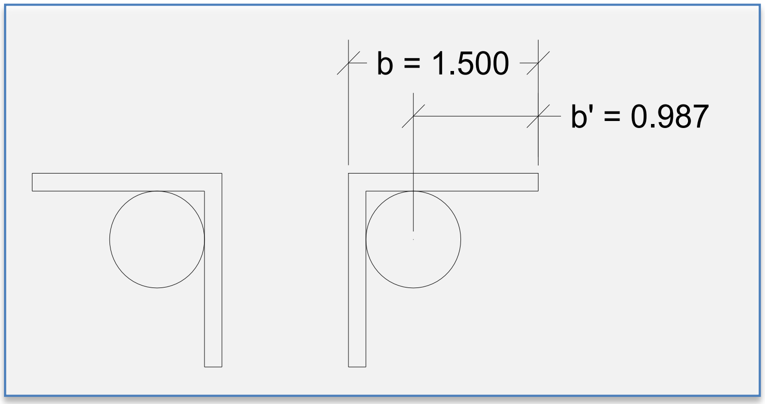
$F_y = 36$ ksi for the rods   Thus, use 36 ksi

Example 3.6 Strengthening of a Joist with Double Angle Webs

Check buckling strength of the composite section (cont'd)

Determine form factor, $Q_{s,}$ per AISC 360-10 E7-1(c).

The calculation for the *unstiffened element* can be done using b, the full angle leg size, or b', the actual *unstiffened element* length as shown in the figure below.



Using b = 1.5 will yield $Q_{s,}$ = 1.0

Example 3.6 Strengthening of a Joist with Double Angle Webs

- Check buckling strength of the composite section (cont'd)
- Compute Slenderness Ratio of Composite Section:

$$L = \sqrt{(6)^2 + (30.028)^2} = 30.62\ in.$$

$$\frac{L}{r} = \frac{30.62}{0.350} = 87.49 < 4.71\sqrt{\frac{29000}{36}} = 133.68$$

$$F_e = \frac{\pi^2(29000)}{\left(\frac{30.62}{0.350}\right)^2} = 37.39\ ksi$$

Example 3.6 Strengthening of a Joist with Double Angle Webs

Check buckling strength of the composite section (cont'd)

(AISC E3-2)

$$F_{cr} = \left[0.658^{\frac{36}{37.39}}\right] 36 = 24.06\ ksi$$

The available axial compressive stress is:

$$F_a = \frac{F_{cr}}{\Omega_c} = 14.41\ ksi$$

The available compressive force is:

$$P_c = (14.41)(1.674) = 24.12\ kips > 18.1\ kips\ required$$

Therefore, OK

Example 3.6 Strengthening of a Joist with Double Angle Webs

Design the Welds

Total force in the welds is determined by

$$P_{rw} = \left(\frac{A_{fr}}{A_t}\right)\left(P_t - P_p\right)$$

$$P_{rw} = \left(\frac{0.884}{1.674}\right)\left(18.1 - 6.9\right) = 5.91\ kips$$

Each of the 3/4” rods has an allowable force of:

(14.41)(0.442) = 6.37 kips

Therefore, use this force for weld design.

Example 3.6 Strengthening of a Joist with Double Angle Webs

- Joint between Rod and Angle will be a partial-penetration flare bevel groove weld.
- Effective throat thickness of 5/16 x rod radius (AISC Spec. Table J2.2)
- Effective throat = (5/16 x 0.75/2) = 0.117 in.
- Allowable weld shear using E70 electrodes is 0.3 x 70.0 x 0.117 = 2.46 kips/in.
- The total req'd weld length to develop the force in each rod is 6.37 / 2.46 = 2.59 in.

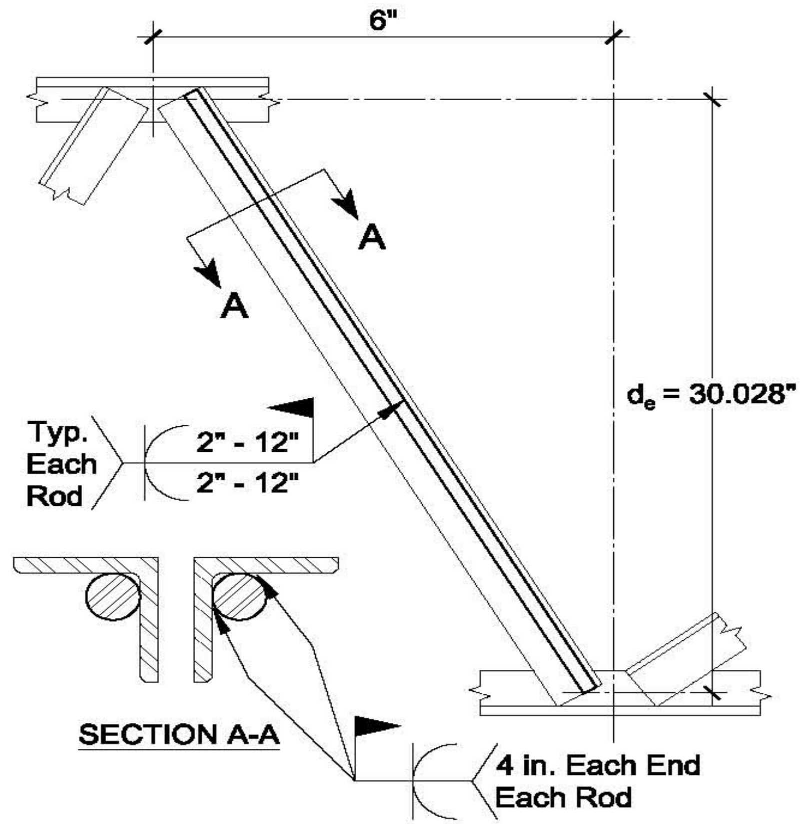
Example 3.6 Strengthening of a Joist with Double Angle Webs

First Compression Web Reinforcing Weld Design (cont'd)

- Use 4 in. of weld at each end as shown in the figure.

  And

- Stitch weld round rods 2" @ 12" on center.



Example 3.6 Strengthening of a Joist with Double Angle Webs

Check Buckling of the Reinforcing Rod between Welds

L = weld spacing – weld length = 12 – 2 = 10 in.

Slenderness ratio of the rod is:

$$\frac{L}{r} = \frac{10}{0.187} = 53.4$$

$$F_e = \frac{\pi^2 (29000)}{\left(\frac{10}{0.187}\right)^2} = 100.09\ ksi$$

(AISC E3-2)

$$F_{cr} = \left[0.658^{\frac{36}{100.09}}\right] 36 = 30.97\ ksi$$

The available axial compressive stress is:

$$F_a = \frac{F_{cr}}{\Omega_c} = \frac{30.97}{1.67} = 18.54\ ksi$$

The available compressive force is:

$$P_c = (18.54)(1.674) = 31.04\ kips > 18.1\ kips\ required$$

Therefore, OK

Chapter 4: Design Approaches for Modifying Joists – Shortening & Lengthening

Factors to Consider

- Even a small increase in length can cause a considerable increase in chord forces
- Web stress reversals may occur
- Joist camber may be adversely affected by removal of any main (diagonal) web member.
- Steps must be taken during modification to maintain camber
- It may often be less expensive to obtain new joist(s)

Design Approaches for Modifying Joists – Shortening & Lengthening

Factors to Consider - **Shortening** a Joist

- Generally, does not require chord reinforcement
- Typically, requires new bearing seats and end webs
- An unacceptable practice is to cut the end of the top chord and bend the existing end web back up to the shortened top chord.

Design Approaches for Modifying Joists – Shortening & Lengthening

Factors to Consider – **Lengthening** a Joist

- Requires the addition to and possibly reinforcing of the top chord and the web members.
  - A splice at the joist center reduces the web splice requirement
  - A splice at the joist end panel reduces the chord splice requirement, but may require web reinforcement
  - A splice at both end panels generally requires no web reinforcement
- If possible, relocate or change the support for the joists so that joist modification is not necessary.

Design Approaches for Modifying Joists – Shortening & Lengthening

Steps to **Shorten** Open Web Steel Joists

1. Steps to Shorten Open Web Steel Joists
   a. Determine the original web layout
   b. Top chord end panel length
   c. Interior panel length
   d. Number of panels
2. Determine where shortened length occurs relative to top chord panels
   a. New end web originates from a bottom chord panel point
   b. Placement angle should be at 45 to 70 degrees from vertical
3. Determine the loading at the shortened length.

Design Approaches for Modifying Joists – Shortening & Lengthening

Steps to **Shorten** Open Web Steel Joists (cont'd)

4. Perform a design on the new length
    a. Compare material required for new length to material for the as-built length
    b. Reinforce undersized existing webs as needed
5. Place new bearing seat at the desired location
    a. Typically, a pair of angles welded between top chord angles
6. Determine the new end web force
    a. Typically, an end web consists of two new angles
    b. Round bars may also be used on smaller K-Series joists with 2 ½" bearing seats

Design Approaches for Modifying Joists – Shortening & Lengthening

Steps to **Lengthen** Open Web Steel Joists

1. Determine the original web layout
    a. Top chord end panel length
    b. Interior panel length
    c. Number of panels
2. Determine where along joist to lengthen relative to top chord panels
    a. Limited to how much length can be added by
        i. Slenderness ratio of new end web
        ii. Long end panel may govern top chord size
3. Determine the loading at the increased length

Design Approaches for Modifying Joists – Shortening & Lengthening

Steps to Lengthen Open Web Steel Joists (cont'd)

4. Perform a design on the new length
   a. Compare material required for new length to material for the as-built length
   b. Reinforce chords and webs as required
5. Place and weld new top chord angles
   a. Use pre-qualified butt weld per AWS or
   b. Splice with new material and a weld sized to develop adequate strength. Splice reinforcement may be needed.

Design Approaches for Modifying Joists – Shortening & Lengthening

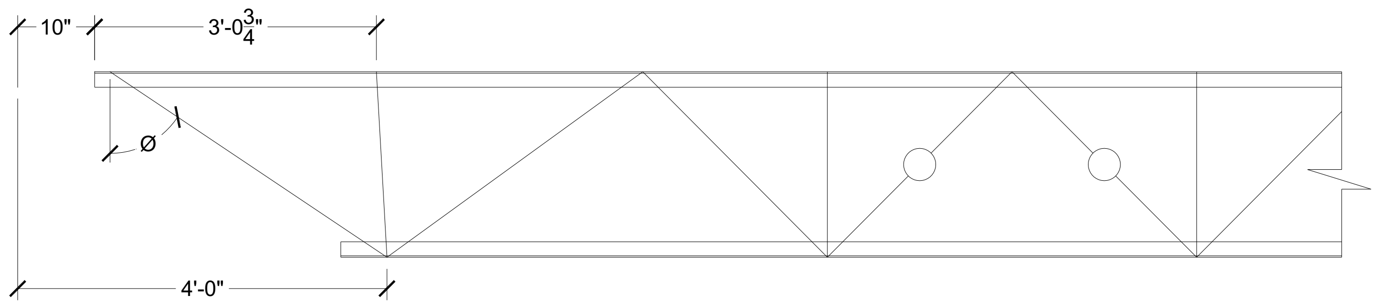
Steps to Lengthen Open Web Steel Joists (cont'd)

6. Place new bearing seat at the desired location
   a. Typically, a back-back angles welded between top chord angles.
7. Determine the new end web force
   a. Typically, an end web consists of two new angles
   b. Round bars may also be used on smaller K-Series joists with 2 ½" bearing seats

Example 4.1 Shortening of a K-Series Joist

Given Conditions

- A 39’-10 ½” long 24K8 joist is to be shortened by 10”
- Approximate angle of new end web:
  - Ø = arctan (48-10-2)/24 = 56.3 degrees



Joist to be Shortened

Example 4.1 Shortening of a K-Series Joist

Analysis and modification

- From the Standard ASD Load Table for Open Web Steel Joists, K-Series
  - New total safe uniform load capacity = 293 plf
- Analysis shows the two circled webs are overstressed
  - Reinforce as needed
  - Existing Webs are crimped angle web members
  - Reinforce with a pair of angles on the outside of the chords

Example 4.1 Shortening of a K-Series Joist

Analysis and modification (cont'd)

- A new bearing seat is required
- Top chord angles are separated by a 1" gap
  - Use 2 - L2x2x3/8" angles 4" long are welded back-to-back to form a 2 ½" deep seat as shown in Fig. 1, or
  - Use 2 - L2x2x¼ angles w/ a ½" spacer plate as shown in Fig. 2.

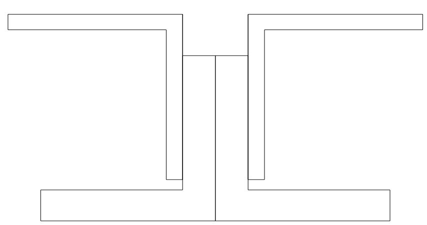


Fig. 1

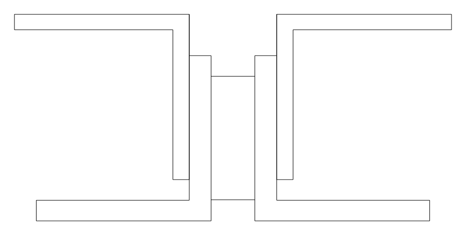


Fig. 2

Example 4.1 Shortening of a K-Series Joist

Analysis and modification (cont'd)

- New end web force is 10,050 lbs
  - New end web length is 37.7 in.
    - Based on clear length between 2" top chord and 1 ¾" bottom chord
  - A pair of 3/4" round bars will satisfy the strength and slenderness criteria
    - L/240 per SJI Specifications for K-Series joists
  - Using E70XX electrodes
    - Flare-bevel groove weld strength with 3/4" rounds = 2.46 kips/in.
    - 10,050/2.46 = 4.1" or 2 ¼" weld at each end of each bar

Example 4.1 Shortening of a K-Series Joist

- Reinforcing Detail

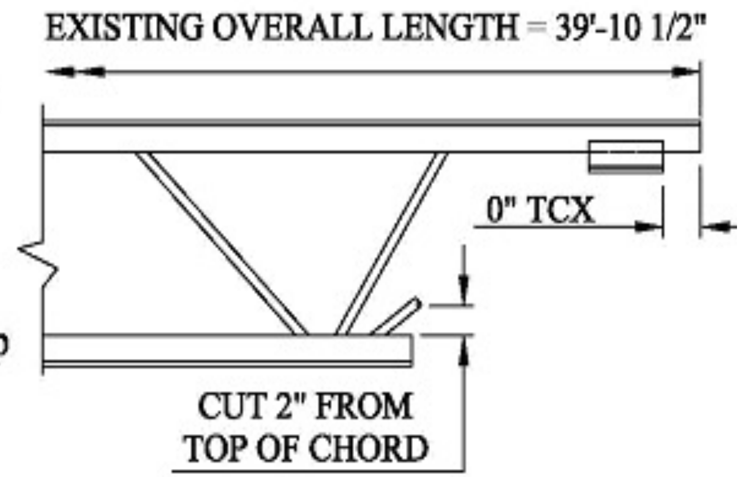
Joist Marks: J22
Total Pcs: 1

Exist O.A.L.: 39'-10 1/2"
Req'd O.A.L.: 39'-00 1/2"

Work Description: Shorten joists 0'-10" by removing top chord.

If work is performed at tag ends leave tag in place.

1. At bottom chord, cut existing end web 2" above top of angles.

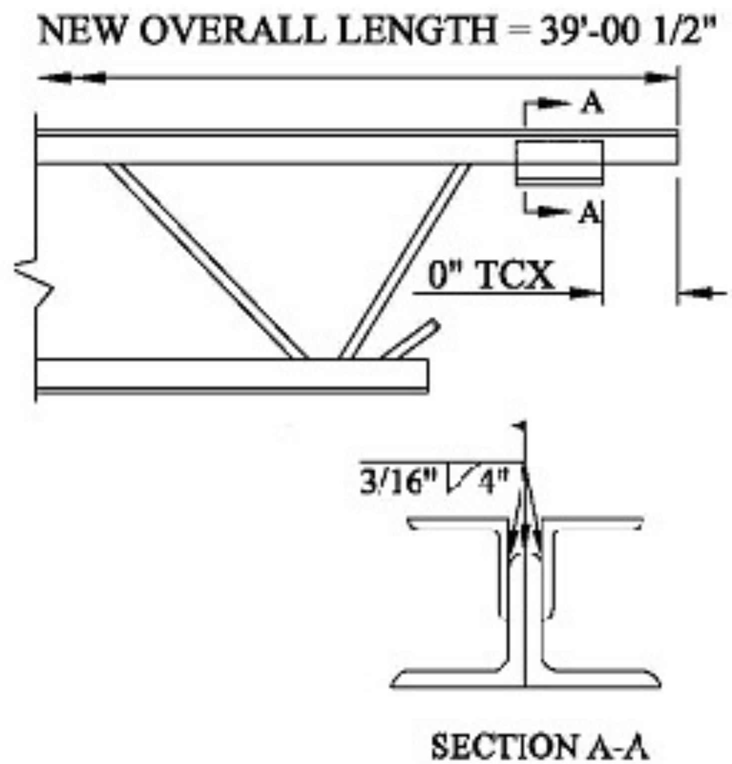


Example 4.1 Shortening of a K-Series Joist

- Reinforcing Detail (cont'd)

2. At top chord, cut top chord back 10" removing web and chord bearings.

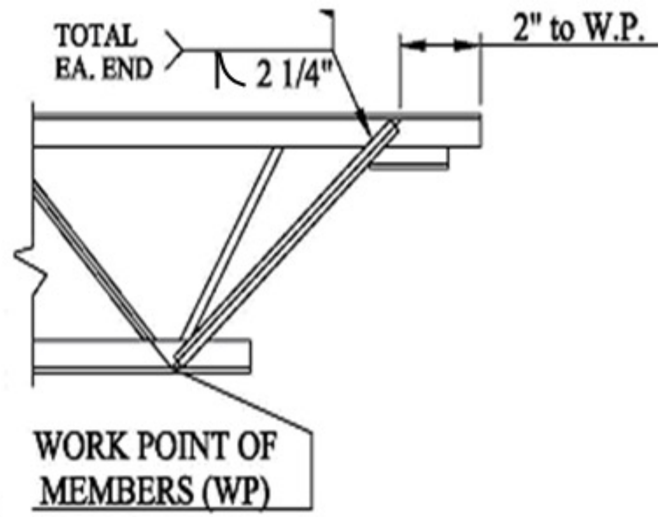
3. Place new bearing angles, 2 x 2 x 3/8 x 0'-4". Weld angles to top chords. See Section A-A.



Example 4.1 Shortening of a K-Series Joist

- Reinforcing Detail (cont'd)

4. Place two (one each side) new end web members, 3/4" rounds. Provide a minimum of 2 1/4" of flare bevel weld at the end of each new end web (total of 4 1/2" for two rounds). Be sure to note placement of new end webs such that the working axis of the end webs is over the first bottom chord knuckle.



Notes:

All weld to be made with E70XX electrodes.
All fillet weld leg lengths equal to new angle thicknesses.
All new material to have a minimum yield strength of $F_y = 36$ ksi.
All welds to be performed by a welder certified to A.W.S. for welds and positions required.
Sketches not to scale.

Chapter 5: Other Considerations

Other Important Considerations

- Deflections
- Camber
- Effects of added loads on bridging
- Creating two joists from one

Other Considerations

Deflections

- Deflection control is often required in addition to strengthening joists for load
- Project deflection requirements must be considered
  - A live load deflection less than L/240 may not be met if a joist is only strengthened for added loads from a snow drift.

Other Considerations

Camber

- When shortening or lengthening a joist, camber needs to be maintained whenever removing any web members

Effects of Added Loads on Bridging

- Bridging may need to be added or altered
  - Providing lateral support to compression chord members is critical
  - Bottom chord may also be subjected to compression due to uplift
- Designer is to refer to the SJI Specifications for bridging requirements

Other Considerations

Creating Two Joists from One

- Similar to shortening a joist
- Due to increased shear and stress reversals
- Many of the webs will likely require reinforcement

Other Examples included in the Digest

- Example 5.1 Changing the Natural Frequency of a Joist System
- Example 5.2 Reducing the Deflection of a Joist Girder

Chapter 6: Summary

Approaches have been Presented for the Modification and Strengthening of Joists

- Several types of reinforcing members presented along with attachment details
- Procedures and details do not constitute an exhaustive list of how to reinforce

They provide the designer with ideas and concepts to solve individual modification and strengthening requirements

SJI Live Webinars

SJI is now offering in-person presentations with PDH/CEU credits awarded to participants

Topics offered include:

- Design of Steel Joist Roofs to Resist Uplift
- Steel Joist Floor Systems – Best Practices
- Joists 101 – Intro to Steel Joist Construction
- Design of Lateral Load Resisting Systems Using Steel Joists & Joist Girders
- Evaluation and Modification of Open Web Steel Joists & Joist Girders

Go to https://steeljoist.org/resources/sji-presents-form/ for more information

Check Out Our Resources

SJI offers a number of resources including:

- Design tools
- Publications
- Live webinars
  - Our next live webinar will be on November 17, 2021
    - Specialty Profiles
- Webinars on demand
  - Our Webinars on Demand section offers 40+ pre-recorded webinars. Earn PDHs today.

Polling Question #2

Is it generally easier to shorten or lengthen a joist?

A) Shorten

B) Lengthen

Q&A SESSION

THANK YOU

Presented by: